IL NUOVO CIMENTO Vol. 33 C, N. 5 Settembre-Ottobre 2010
DOI 10.1393/ncc/i2011-10719-y

Colloquia: LaThuile10

Early data from the LHCb experiment

U. Kerzel(*)
Cavendish Laboratory (HEP) - JJ Thomson Avenue, Cambridge, CB3 0HE, UK

(ricevuto il 14 Settembre 2010; pubblicato online l'11 Gennaio 2011)

Summary. — The LHCb experiment at the Large Hadron Collider (LHC) has been optimised for high-precision measurements of the charm and beauty sector. This talk summarised the first results obtained from the pilot run of the LHC at the end of 2009.

PACS 07.05.-t – Computers in experimental physics.
PACS 13.25.-k – Hadronic decays of mesons.
PACS 13.30.-a – Decays of baryons.
PACS 13.20.-v – Leptonic, semileptonic, and radiative decays of mesons.

1. – Introduction

The LHCb experiment [1] is one of the four major experiments at the Large Hadron Collider (LHC) and focuses on detailed studies of decays of charm and bottom hadrons. Its main objective is to determine precisely and over-constrain the parameters of the CKM matrix, and to search for further sources of CP violation and New Physics beyond the Standard Model in rare B- and charm hadron decays.

Particles containing charm and bottom quarks are produced mainly in the forward (or backward) direction which motivates the design of the LHCb experiment as a single-arm forward spectrometer as illustrated in fig. 1.

Its main features are a high-precision silicon vertex detector, tracking stations, electromagnetic and hadronic calorimeters, muon detectors and two Ring-Imaging Cherenkov (RICH) detectors which provide excellent particle identification capabilities between approximately 2 to 100 GeV/c.

2. – Performance with first data

During the pilot run in 2009, approximately 26000 proton-proton collisions were recorded by the LHCb experiment for which all sub-detectors were operational and in

(*) On behalf of the LHCb Collaboration.

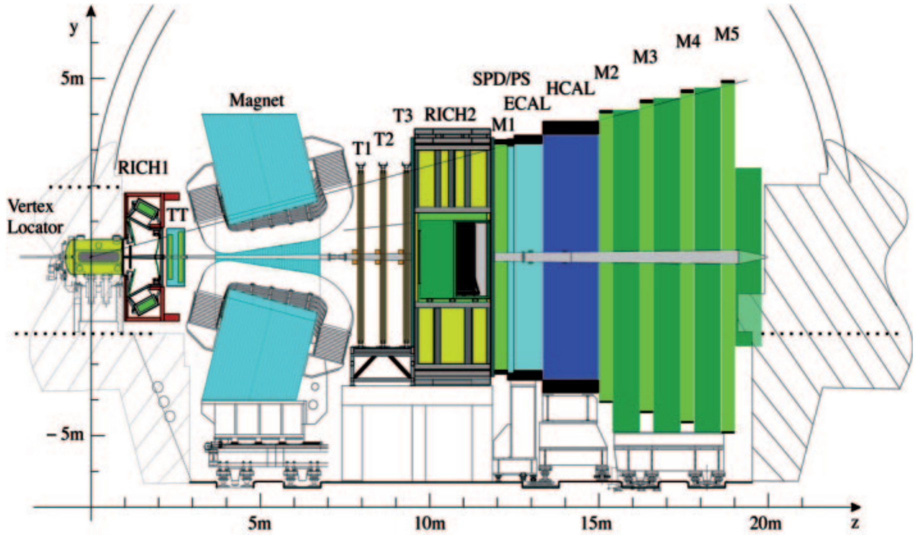

Fig. 1. – Schematic overview of the LHCb experiment.

stable running conditions. More than 99% of all read-out channels in each sub-detector were operational during the pilot run. Special care has to to be taken when including the vertex-detector (VELO) in the detector read-out: the VELO consists of 21 stations of silicon wafers with R and Φ readout arranged on two retractable detector halves inside the beam vacuum. During injection and beam setup, both halves are retracted by 30 mm from the nominal beam position in a safe position behind the LHC collimator aperture. During nominal data-taking conditions, both halves are then successively moved closer to the beam until they are 8 mm away from the nominal beam line. The detector modules were closed to 15 mm from this nominal position during the pilot run as the lower energy of the proton beam could potentially reach the nominal detector position in case of a misbehaviour of some beam optic magnets. Figure 2 shows the distribution of the vertex resolution as a function of the track multiplicity in the first data.

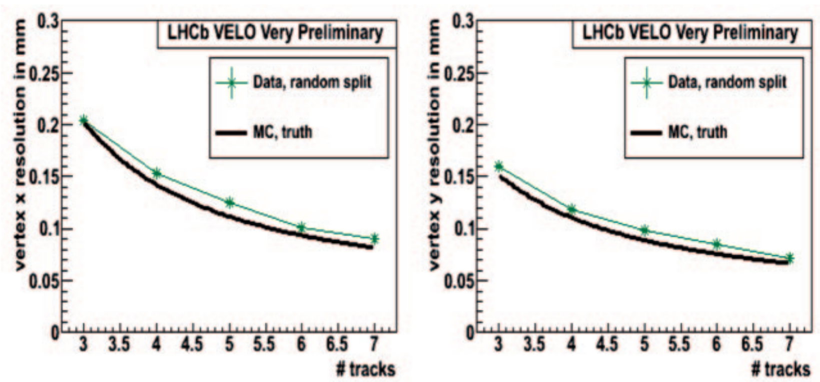

Fig. 2. – Vertex detector resolution as a function of track multiplicity (VELO 15 mm from nominal position). The expectation from simulation is overlaid.

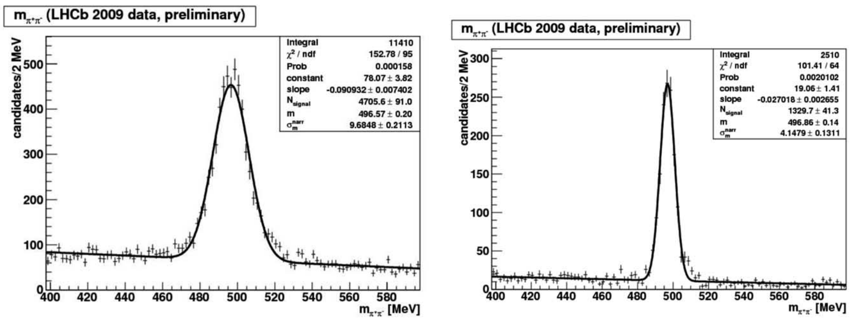

Fig. 3. – The decay $K_s \to \pi\pi$ without (left) and with (right) VELO information.

The improvement in the mass resolution obtained by including data recorded by the (half-closed) VELO is illustrated by reconstructing the decay $K_s \to \pi\pi$ (fig. 3) and $\Lambda \to p\pi$ (fig. 4): The width of a single Gaussian function fitted to the invariant mass distribution reduces from $\sigma = 2.6 \pm 0.1$ (stat.) MeV/c^2 to $\sigma = 1.4 \pm 0.1$ (stat.) MeV/c^2 in the case of the K_s and from $\sigma = 9.7 \pm 0.2$ (stat.) MeV/c^2 to $\sigma = 4.1 \pm 0.1$ (stat.) MeV/c^2 in the case of the Λ. Although the amount of data collected so far does not yet allow a full alignment of the LHCb detector, the obtained widths of the distributions are already very close to the expectations from simulated events. The central values of the mass peaks agree with the current world average (obtained from the Particle Data Group), indicating that the detector material is correctly described in the reconstruction software and the magnetic field is well calibrated.

Figure 5 illustrates the excellent performance of the calorimeter showing reconstructed decays of $\pi^0 \to \gamma\gamma$ and $\eta \to \gamma\gamma$.

The efficiency measured by the muon system exceeds 99% and the measured invariant di-muon mass spectrum is shown in fig. 6. Due to the low yield of di-muon events in the data recorded during the pilot run, a more quantitative evaluation will be done with the data recorded in 2010.

Highly efficient particle identification is of vital importance to most physics analyses being prepared by the LHCb experiment. The LHCb spectrometer features two Rich Imaging Cherenkov (RICH) detectors which offer unique particle identification capabilities over a large momentum range. As particles traverse the radiator material, Cherenkov

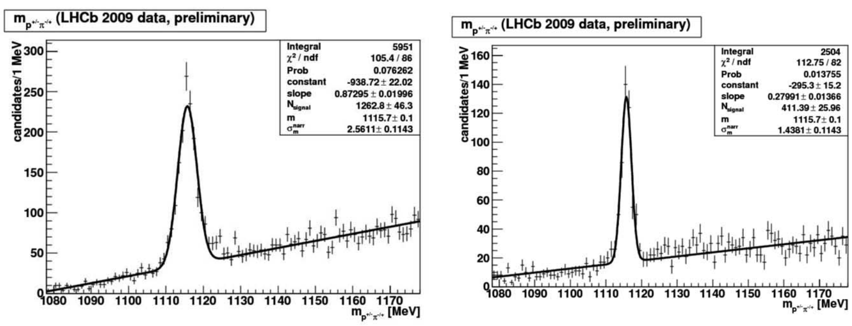

Fig. 4. – The decay $\Lambda \to p\pi$ without (left) and with (right) VELO information.

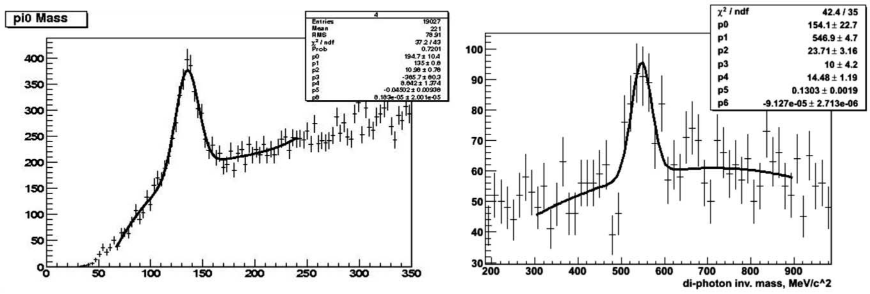

Fig. 5. – The decays $\pi^0 \to \gamma\gamma$ (left) and $\eta^0 \to \gamma\gamma$ measured in the calorimeter (LHCb preliminary).

light is being emitted which is then detected by photo-detectors. Together with momentum information obtained from the tracking system, the resulting rings allow to deduce the particle species from the size of the measured Cherenkov ring as illustrated in fig. 7. Figure 8 shows the invariant mass spectrum of $\Phi \to KK$ candidates: Starting from all candidates (left), a clean mass peak is obtained after selecting tracks compatible with the kaon mass hypothesis (right).

3. – LHCb physics programme

The LHCb physics programme focuses on discovering New Physics beyond the current understanding in the context of the Standard Model by performing precision measurements of charm and bottom quarks. The physics analyses focus on measurements related to:

- CP violation (*e.g.*, quark mixing, CKM angle $\gamma, \ldots$),
- Rare decays (*e.g.*, $B_s \to \mu^+\mu^-$, $B \to K^*\mu^+\mu^-, \ldots$)
- Flavour physics (*e.g.*, spectroscopy, electro-weak physics, soft QCD, ...

A detailed summary of the key analyses is given in the physics road-map document [2].

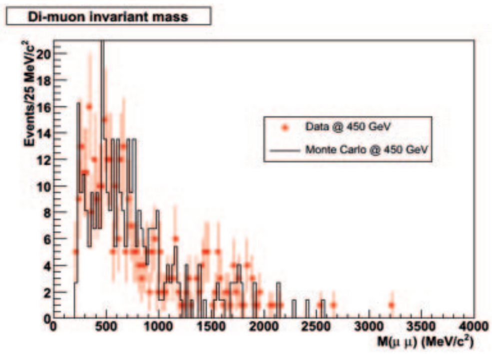

Fig. 6. – Invariant di-muon mass spectrum (LHCb preliminary). The predictions from simulation are overlaid.

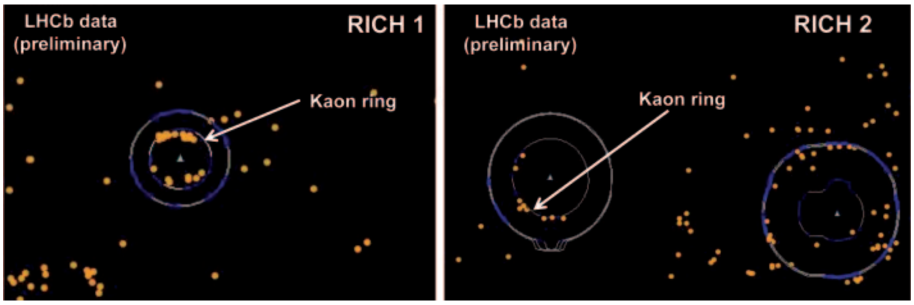

Fig. 7. – Reconstructed Cherenkov photons with expected distribution for a given mass hypothesis.

3˙1. *2009 data.* – The analysis of the data recorded during the LHC pilot run is not only vital to the commissioning and understanding of the detector but also offers unique opportunities for physics measurements. Due to its unique rapidity range between $2 \leq \eta \leq 5$, data recorded by the LHCb experiment is a key ingredient in improving and tuning event simulations used in physics analyses. Studies investigating the charged track multiplicities, the cross-section of K_s and Λ meson production as a function of p_t and η, as well as the ratio of the Λ *vs.* $\bar{\Lambda}$ production are currently in progress.

3˙2. *Charm physics.* – Analyses focusing on decays involving the charm quark offer unique potential to discover New Physics beyond the Standard Model in the early phase of LHCb operation as the charm quark production cross-section is approximately seven times larger than the one for the bottom quark. $4 \cdot 10^6$ $D^{*+} \to D^0(K^+K^-)\pi^+$ decays are expected to be recorded per $100\,\text{pb}^{-1}$ integrated luminosity which is competitive to the sample currently available to the BaBar Collaboration [3]. The extensive charm physics programme of the LHCb Collaboration focuses on the discovery of rare decays such as $D^0 \to \mu^+\mu^-$ and observation of CP violation in decays such as $D^0 \to K^+K^-$ and $D^0 \to K^+\pi^-$. One of the first key analyses is a detailed measurement of the relative lifetime $\tau(D^0 \to K^+\pi^-)$ *vs.* $\tau(D^0 \to K^+K^-)$ which is related to the quantity y_{CP} in the theory of D^0 meson mixing. Although no single measurement has been able to establish the mixing of D^0 meson mixing to better than 5σ, the combination of all available data shows compelling evidence [4]. The direct observation of charm

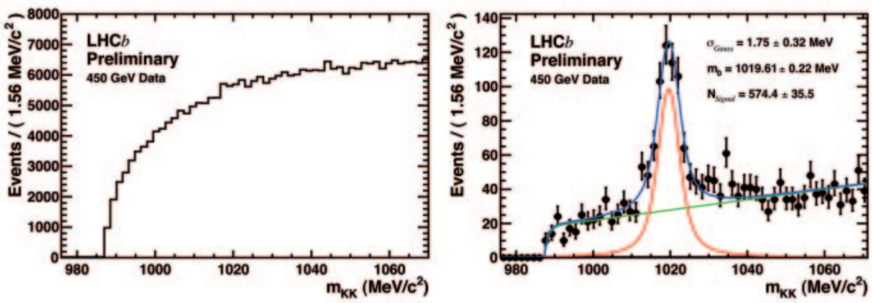

Fig. 8. – Invariant KK mass spectrum without particle ID (left) and with particle ID (right).

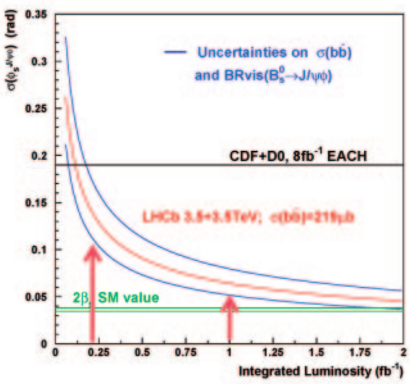

Fig. 9. – Sensitivity of the analysis of the angle Φ_s. The arrows indicate the projected integrated luminosity recorded by the end of 2010 ($200\,\mathrm{pb}^{-1}$) and at the end of 2011 ($1\,\mathrm{fb}^{-1}$).

meson mixing plays a vital role in understanding and constraining particular New Physics models (see, *e.g.* [5]).

Due to the lower energy and luminosity delivered by the LHC in the early running, the trigger thresholds have been optimised in the low luminosity regime ($\mathcal{L} < 10^{31}\,\mathrm{s}^{-2}\,\mathrm{cm}^{-1}$) to improve the number of recorded prompt charm events by a factor ≈ 4 without impact on the B physics performance. This is achieved by lowering the thresholds on the transverse momentum and impact parameter of the tracks forming the charm meson candidate. The resulting higher background is manageable since the computing capability of the trigger farm is designed for higher luminosities.

3·3. *Beauty physics*. – The analysis of decays of beauty hadrons is the main research area of the LHCb experiment. A multitude of analyses are currently being prepared in anticipation of the beginning of data-recording in spring 2010. Two example analyses are highlighted which offer high potential to discover New Physic with data recorded in 2010/11.

3·4. $B_s \to J/\psi\Phi$. – The decay $B_s \to J/\psi\Phi$ is sensitive to the mixing phase Φ_S in the heavy quark sector and is the counter-part to the "golden-mode" decay $B^0 \to J/\psi K_s$. This decay mode is very sensitive to the existence of New Physics as the value of Φ_s calculated within the Standard Model is very small and precisely known: $\Phi_s = -2\beta_s = -arg(V_{ts}^2) = -0.036 \pm 0.002$ [2]. The current analyses performed by the CDF and D0 Collaborations at the Tevatron [6] show a 2σ tension w.r.t. the value expected within the Standard Model which may indicate that New Physics is "around the corner". Figure 9 illustrates that—depending on Nature—New Physics may already be discovered using the data recorded in 2010. Experimentally, this analysis is very challenging as two CP-even and one CP-odd state have to be disentangled in an angular analyses. Excellent particle identification and vertex resolution capabilities are crucial ingredients to this analysis and the study of the data recorded during the pilot run confirms that the LHCb experiment is in excellent shape.

3·5. $B_s \to \mu^+\mu^-$. – The decay $B_s \to \mu^+\mu^-$ is extremely rare in the Standard Model as its branching fraction is calculated to be $(3.35 \pm 0.32) \cdot 10^{-9}$ [7]. However, many

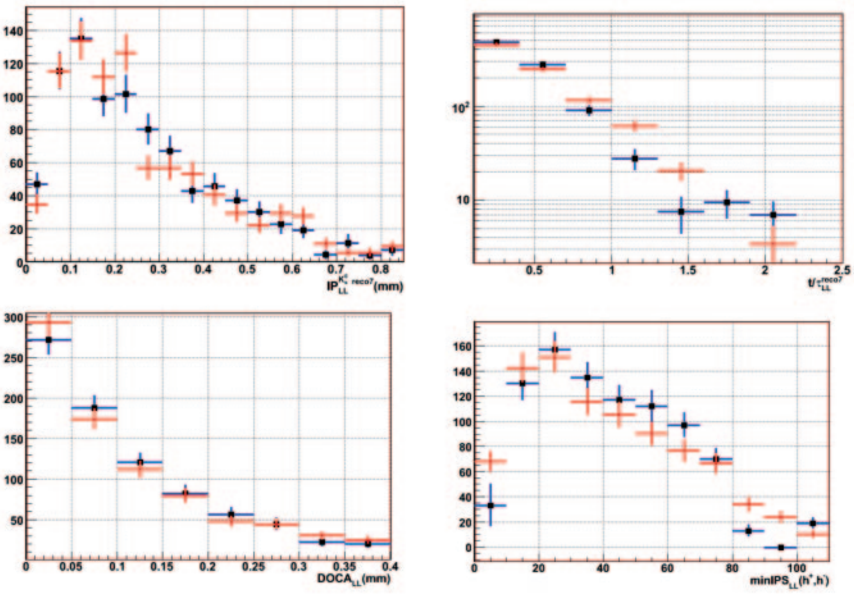

Fig. 10. – (Colour on-line) Agreement between data and simulated events for the key quantities entering the geometrical likelihood using the decay $K_s \to \pi^+\pi^-$. The figures show the distribution of the K_s impact parameter (top left), the K_s lifetime (top right), the distance of closest approach of the two pion tracks (bottom left) and the minimal impact parameter of the pion tracks (bottom right) forming the K_s candidate. Simulated events are shown in red, data recorded during the LHC pilot run in blue.

New Physics scenarios (*e.g.*, super-symmetry) lead to a greatly enhanced branching ratio and hence any observation of this decay in the early LHCb data would immediately imply the discovery of New Physics. The main experimental challenge of this analysis is the efficient rejection of background which is done by a geometrical likelihood. Key ingredients in this likelihood are the vertex separation, mass resolution and the pointing constraint of the two muon candidates. Since no $B_s \to \mu^+\mu^-$ candidate is expected in the data recorded during the pilot run, the analysis strategy is exercised using the decay $K_s \to \pi^+\pi^-$ which allows to test all elements of the analysis chain with real data instead of simulated events. The quantities used in the geometrical likelihood agree well with expectations from simulated events as shown in fig. 10.

Figure 11 illustrates the discovery potential for this analysis as the value predicted by the Standard Model will (almost) be reached with the projected integrated luminosity recorded by the end of the 2010/11 data-taking.

4. – Conclusion

The LHCb experiment started very successfully recording data in the LHC pilot run of 2009. All sub-detectors are ready and in excellent shape. The first "standard candles" such as K_s, Λ and Φ mesons have been reconstructed which demonstrates that both the data-acquisition and event reconstruction software, as well as the detector hardware, are ready for the physics analyses currently being prepared. The ongoing studies of the initial data taken during the pilot run of the LHC confirm that the LHCb experiment

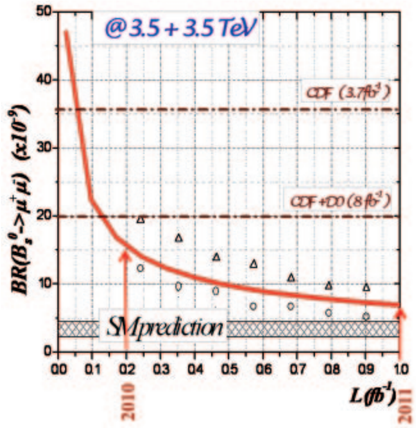

Fig. 11. – Sensitivity of the analysis of decay $B_s \to \mu^+\mu^-$. The arrows indicate the projected integrated luminosity recorded by the end of 2010 ($200\,\mathrm{pb}^{-1}$) and at the end of 2011 ($1\,\mathrm{fb}^{-1}$).

is meeting the stringent design criteria. The integrated luminosity available for physics analysis is projected to be up to $200\,\mathrm{pb}^{-1}$ by the end of 2010 and up to $1\,\mathrm{fb}^{-1}$ by the end of 2011 which will make the LHCb experiment very soon competitive with both the B-factories BaBar and Belle, as well as the Tevatron experiments CDF and D0. Sensitivity studies based on simulated events illustrate that New Physics may already be discovered early in the data-taking.

REFERENCES

[1] The LHCb Collaboration, *JINST*, **3** (2008) S08005.
[2] The LHCb Collaboration, arXiv hep-ex 0912.4179 (2009).
[3] The BaBar Collaboration, *Phys. Rev. D*, **80** (2009) 071103.
[4] Heavy Flavour Averaging Group, `http://www.slac.stanford.edu/xorg/hfag`.
[5] Petrov A., *Proceedings of Science*, arXiv:1003.0906 (2010).
[6] CDF and D0 Collaborations, Public note, CDF9787, D0 5928-CONF (2009).
[7] Blanke M., Buras A., Guadagnoli D. and Tarantino C., *JHEP*, **610** (2006) 003.