First Mass Measurements at LHCb

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Abstract. The masses of the b-hadrons and the X(3872) have been measured using 35 pb^{-1} of data collected during the 2010 physics run with the LHCb detector at a centre-of-mass energy of 7 TeV. The analyses are based on the exclusive decays $B^+ \to J/\Psi K^+$, $B^0 \to J/\Psi K^{*0}$, $B^0 \to J/\Psi K^0_S$, $B^0_s \to J/\Psi \phi$, $\Lambda_b \to J/\Psi \Lambda$, $B^+_c \to J/\Psi \pi^+$ and $X(3872) \to J/\Psi \pi^+\pi^-$, respectively. The momentum scale is calibrated using $J/\Psi \to \mu^+\mu^-$ decays.

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INTRODUCTION

The masses of baryons and mesons are experimentally observable properties that can be confronted with theoretical predictions for QCD. The recent observation of strange b-baryons at the Tevatron experiments [1] [2] has renewed the interest in hadron spectroscopy.

The X(3872) was first observed by the Belle Collaboration in the decay $B^\pm \to X(3872)K^\pm$, $X(3872) \to J/\Psi \pi^+\pi^-$ [3], and later confirmed by BaBar [4], CDF [5] and DØ [6]. Its nature, however, remains uncertain: It is not excluded that it is a conventional charmonium state like the $\eta_{c2}(1D)$ meson, but it could also be a tetraquark state or a $D^{*0}\bar{D}^0$ molecular state with the mass being very close to the threshold.

DATA SAMPLES AND EVENT SELECTION

The analyses use an integrated luminosity of $\approx$ 35 pb^{-1} of pp-collision data recorded with the LHCb detector [7] at a centre-of-mass energy $\sqrt{s}$ = 7 TeV between July and October 2010. All detector components were fully operational and in stable conditions. The dataset consists of two sub-samples recorded with opposite directions of the magnetic field in the dipole magnet of LHCb, where each has an integrated luminosity of $\approx$ 17 pb^{-1}.

For the b-hadron mass measurements, the decays $B^+ \to J/\Psi K^+, B^0 \to J/\Psi K^{*0}, B^0 \to J/\Psi K^0_S, B^0_s \to J/\Psi \phi$, $\Lambda_b \to J/\Psi \Lambda$, $B^+_c \to J/\Psi \pi^+$ were considered.[1] The candidates were selected using cuts on the vertex- and track quality, impact parameter, particle identification, momentum, transverse momentum and lifetime. No restriction on the trigger the candidate passed was made. To improve the mass resolution, the J/Ψ,

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[1] Charge-conjugate modes are implied.

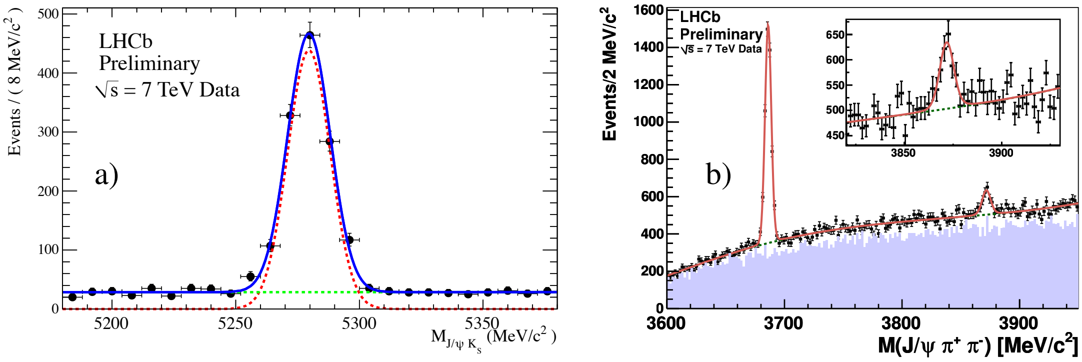

FIGURE 1. a) Invariant mass distribution of $J/\Psi K_S^0$ (black points with statistical error bars), with the J/Ψ mass constrained to its nominal value. The grey curve is the result of the fit. b) Invariant mass distribution of $J/\Psi\pi^+\pi^-$ (black points with statistical error bars) and $J/\Psi\pi^\pm\pi^\pm$ (grey filled histogram), with the J/Ψ masses constrained to their nominal value. The grey curve is the result of the fit.

K_S^0 and Λ masses were constrained to their known values [8] in the vertex fit of the respective decay.

The X(3872) selection uses similar cuts to that for the b-hadrons (except the lifetime cut). As in the b-hadron mass measurements, the J/Ψ is constrained to its known value. In addition to the $X(3872) \to J/\Psi\pi^+\pi^-$ sample, a $\Psi(2S) \to J/\Psi\pi^+\pi^-$ sample (used as a control channel) and a $\Psi(2S) \to J/\Psi\pi^\pm\pi^\pm$ sample (used to describe the background coming from a real J/Ψ and a random combination of two pions) are selected as well, using the same cuts as described before.

MOMENTUM SCALE CALIBRATION AND ALIGNMENT

The knowledge of the momentum scale is a crucial ingredient to precise mass measurements. For all considered decays, the momentum scale is calibrated using a large sample of $J/\Psi \to \mu^+\mu^-$ decays. After calibration, the relative difference between the measured average mass of the J/Ψ and the known value is $2 \cdot 10^{-5}$, which is well below the systematic uncertainty on the momentum scale factor itself. The momentum scale factor is applied to all measurements of the track momenta and accounts for effects related to the knowledge of the magnetic field map and the alignment of the tracking system. The calibration is checked on the $\Upsilon(1S), D^0, K_S^0$ two-body decays as well as on $\Psi(2S) \to J/\Psi\pi^+\pi^-$ and shown to be valid.

The measured J/Ψ mass after alignment and calibration is checked to be stable over the whole 2010 data-taking period.

FIT FUNCTIONS

For the b-hadron mass measurements, a Gaussian signal component and an exponential background component is used. For the X(3872) measurement, the background is described by:

$$F_{bg}(M;m_r,c_0,c_1,c_2) = \frac{1}{a}(M-m_r)^{c_0}e^{-Mc_1-M^2c_2} \quad (1)$$

where a is a normalisation factor, m_r is the threshold of the distribution and c_0,c_1,c_2 describe the shape of the background. The $\Psi(2S)$ and the $X(3872)$ signals are each described with a Voigt function (a convolution of a non-relativistic Breit-Wigner and a Gaussian). The width of the $\Psi(2S)$ is fixed to its PDG value (0.317 MeV/c^2) [8] while the width of the X(3872) is set to 1.3 MeV/c^2, which is the prefered value given by the CDF combination of the BaBar and Belle measurements [9] [3] [10]. The invariant mass distributions and the results of the fits for $B^0 \to J/\Psi K_S^0$ and $X(3872) \to J/\Psi\pi^+\pi^-$ are shown in fig. (1).

SYSTEMATIC UNCERTAINTIES

The following sources of systematic uncertainties were considered:

- **Mass fitting:** For the b-hadron mass measurements, fits were also performed using a double Gaussian signal and / or a flat background. The difference of these results with respect to the ones mentioned in the section before were assigned as a systematic uncertainty.
  For the X(3872) mass measurement, the fits were performed varying the width of the X(3872) resonance from 0 to 2.6 MeV/c^2, as the natural width is poorly known. The difference in the mass to the central value of 3871.96 MeV/c^2 is then assigned as a systematic uncertainty. The error on the background modelling is estimated comparing the results of fits to signal Monte Carlo events with or without additional background combinations given by the $\Psi(2S) \to J/\Psi\pi^+\pi^+$ same sign data sample.
- **Momentum calibration:** The momentum scale was varied by the uncertainty of 0.1 per mille quoted on the calibration based on the observed mass of the K_S^0 relative to the PDG. The difference of the result with respect to the central value was taken as a systematic uncertainty. In addition, a dependence of the J/Ψ mass on the pseudorapidity of the daughter particles is observed. To access the impact of this the variation was parameterized and applied to the data. The difference of the mass observed in this test with respect to the central value is taken as a systematic uncertainty.
- **Detector description:** To account for the uncertainty of the energy loss experienced by a particle traversing the detector, the amount of material in the detector is scaled by 10% and the analyses are repeated. The difference to the nominal results is taken as a systematic uncertainty.
- **Detector alignment:** To check the alignment, the track slopes are changed by one per mille, accounting for the uncertainty of the length scale of the detector along the beam axis. The effect on the measured masses is taken as a systematic uncertainty. A further check is done by excluding hits from the tracking station before the magnet and redoing the track fit. No difference is observed and the statistical precision of this test is assigned as a systematic uncertainty.

TABLE 1. Summary of the measured masses of the b-hadrons and the X(3872) state.

Decay mode	Mass (MeV/c^2)	Stat. error (MeV/c^2)	Sys. error (MeV/c^2)
$B^+ \to J/\Psi K^+$	5279.27	0.11	0.20
$B^0 \to J/\Psi K^{*0}$	5279.54	0.15	0.16
$B^0 \to J/\Psi K^0_S$	5279.61	0.29	0.20
$B^0_s \to J/\Psi \phi$	5366.60	0.28	0.21
$\Lambda_b \to J/\Psi \Lambda$	5619.49	0.70	0.19
$B^+_c \to J/\Psi \pi^+$	6268.0	4.0	0.6
$X(3872) \to J/\Psi \pi^+ \pi^-$	3871.96	0.46	0.10

RESULTS

The results of the mass measurements of the b-hadrons and the X(3872) and their respective statistical and systematical errors are presented in table (1). The mass measurements for B_u, B_d, B_s and Λ_b are currently the most precise in the world.

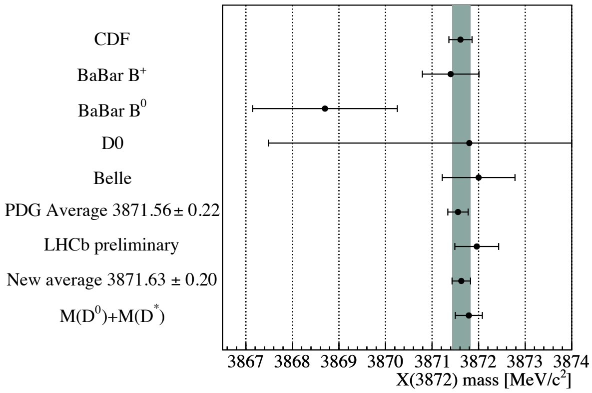

FIGURE 2. Comparison of the measured X(3872) mass in the $J/\Psi\pi^+\pi^-$ mode by the Belle [3], DØ [6], BaBar [9] and CDF [10] collaborations, compared with the preliminary LHCb result. The averages are performed following the prescription given in [8].

The comparison of the measured mass of the X(3872) between Belle, BaBar, CDF, DØ and LHCb is shown in fig. (2). It can be seen that LHCb is already statistically competitive given its limited dataset.

REFERENCES

1. V. Abazov, et al., *Phys.Rev.Lett.* **99**, 052001 (2007).
2. T. Aaltonen, et al., *Phys.Rev.* **D80**, 072003 (2009).
3. S. Choi, et al., *Phys.Rev.Lett.* **91**, 262001 (2003).
4. B. Aubert, et al., *Phys.Rev.* **D71**, 071103 (2005).
5. D. E. Acosta, et al., *Phys.Rev.Lett.* **93**, 072001 (2004).
6. V. Abazov, et al., *Phys.Rev.Lett.* **93**, 162002 (2004).
7. A. Alves, et al., *JINST* **3**, S08005 (2008).
8. K. Nakamura, et al., *J.Phys.G* **G37**, 075021 (2010).
9. B. Aubert, et al., *Phys.Rev.* **D77**, 111101 (2008).
10. T. Aaltonen, et al., *Phys.Rev.Lett.* **103**, 152001 (2009).