**Measurement of the differential branching fraction of the decay \(^{0}\text{b}^{+}\)**

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Measurement of the differential branching fraction of the decay $\Lambda_b^0 \to \Lambda \mu^+ \mu^-$

LHCb Collaboration

1. Introduction

The decay $\Lambda_b^0 \to \Lambda \mu^+ \mu^-$ is a rare ($b \to s$) flavour-changing neutral current process that in the Standard Model proceeds through electroweak loop (penguin and $W^\pm$ box) diagrams. Since non-Standard Model particles may also participate in these loop diagrams, measurements of this and similar decays can be used to search for physics beyond the Standard Model. In the past, more emphasis has been placed on the study of rare decays of mesons than of baryons, in part due to the theoretical complexity of the latter [1]. In the particular system studied in this Letter, the decay products include only a single hadron, simplifying the theoretical modelling of hadronic physics in the final state.

The study of $\Lambda_b^0$ baryon decays is of considerable interest for two reasons. Firstly, as the $\Lambda_b^0$ baryon has non-zero spin, there is the potential to improve the limited understanding of the helicity structure of the underlying Hamiltonian, which cannot be extracted from mesonic decays [1,2]. Secondly, as the composition of the $\Lambda_b^0$ baryon may be considered as the combination of a heavy quark with a light diquark system, the hadronic physics differs significantly from that of the $B$ meson decay. This may allow this aspect of the theory to be tested, which may lead to improvements in understanding of $B$ mesons.

Theoretical aspects of the $\Lambda_b^0 \to \Lambda \mu^+ \mu^-$ decay have been considered both in the SM and in various scenarios of physics beyond the Standard Model [3–15]. Although based on the same effective Hamiltonian as that for the corresponding mesonic transitions, the hadronic form factors for the $\Lambda_b^0$ baryon case are less well-known due to the smaller number of experimental constraints.

This leads to a large spread in the predicted branching fractions. The differential branching fraction as a function of the square of the dimuon invariant mass, $q^2$, is measured as a function of the $J/\psi$ mass, while at lower-$q^2$ values upper limits are set on the differential branching fraction. Integrating the differential branching fraction over $q^2$, while excluding the $J/\psi$ and $\psi(2S)$ regions, gives a branching fraction of $B(\Lambda_b^0 \to \Lambda \mu^+ \mu^-) = (0.96 \pm 0.16 \text{(stat)} \pm 0.13 \text{(syst)} \pm 0.21 \text{(norm)}) \times 10^{-6}$, where the uncertainties are statistical, systematic and due to the normalisation mode, $\Lambda_b^0 \to J/\psi A$, respectively.

The first observation of the decay $\Lambda_b^0 \to \Lambda \mu^+ \mu^-$ by the CDF Collaboration [16] had a signal yield of $24 \pm 5$ events, corresponding to an absolute branching fraction of $1.73 \pm 0.42 \text{(stat)} \pm 0.55 \text{(syst)} \times 10^{-6}$, with evidence for signal at $q^2$ above the square of the mass of the $\psi(2S)$ resonance.

Following previous measurements of rare decays involving dimuon final states [17,18], a first measurement by LHCb of the differential and total branching fractions for the rare decay $\Lambda_b^0 \to \Lambda \mu^+ \mu^-$ is reported. The inclusion of charge conjugate modes is implicit throughout. The rates are normalised with respect to the $\Lambda_b^0 \to J/\psi A$ decay, with $J/\psi \to \mu^+ \mu^-$. This analysis uses a $pp$ collision data sample, corresponding to an integrated luminosity of $1.0 \text{ fb}^{-1}$, collected during 2011 at a centre-of-mass energy of 7 TeV.

2. Detector and software

The LHCb detector [19] is a single-arm forward spectrometer covering the pseudorapidity range $2 < \eta < 5$, designed for the study of particles containing $b$ or $c$ quarks. The detector includes a high-precision tracking system consisting of a silicon-strip vertex detector (VELO) surrounding the $pp$ interaction region, a large-area silicon-strip detector located upstream of a dipole magnet with a bending power of about 4 Tm, and three stations of silicon-strip detectors and straw drift tubes placed downstream. The combined

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tracking system provides a momentum measurement with relative uncertainty that varies from 0.4% at 5 GeV/c to 0.6% at 100 GeV/c, and impact parameter (IP) resolution of 20 μm for tracks with high transverse momentum. Charged hadrons are identified using two ring-imaging Cherenkov detectors [20]. Photon, electron and hadron candidates are identified by a calorimeter system consisting of scintillating-pad and preshower detectors, an electromagnetic calorimeter and a hadronic calorimeter. Muons are identified by a system composed of alternating layers of iron and multiwire proportional chambers [21].

The trigger [22] consists of a hardware stage, based on information from the calorimeter and muon systems, followed by a software stage, which applies a full event reconstruction. Candidate events are first required to pass a hardware trigger which selects muons with a transverse momentum, \( p_T > 1.48 \) GeV/c. In the subsequent software trigger, at least one of the final state particles is required to have both \( p_T > 0.8 \) GeV/c and an impact parameter greater than 100 μm with respect to all of the primary pp interaction vertices (PVs) in the event. Finally, the tracks of two or more of the final state particles are required to form a vertex that is significantly displaced from the PVs in the event.

A candidate \( \Lambda^0 \rightarrow \mu^+\mu^- \) or \( \Lambda^0 \rightarrow J/\psi \Lambda \) decay that is directly responsible for triggering both the hardware and software triggers is denoted as “trigger on signal”. As these two categories of events are not mutually exclusive, the overlap may be used to estimate the efficiency of the trigger selection directly from data.

In the simulation, pp collisions are generated using PYTHIA 6.4 [23] with a specific LHCb configuration [24]. Decays of hadronic particles are described by EvtGen [25] in which final state radiation is generated using PHOTOS [26]. The interaction of the generated particles with the detector and its response are implemented using the GEANT4 toolkit [27,28] as described in Ref. [29].

3. Candidate selection

Candidate \( \Lambda^0 \rightarrow \mu^+\mu^- \) (signal mode) and \( \Lambda^0 \rightarrow J/\psi \Lambda \) (normalisation mode) decays are reconstructed from muon, \( \Lambda \) baryon and \( J/\psi \) candidates. The \( J/\psi \) candidates are reconstructed via their dimuon decays and therefore the \( \Lambda^0 \rightarrow J/\psi \Lambda \) decay is an ideal normalisation process. The dimuon candidates are formed from two oppositely-charged particles identified as muons [21,20]. Good track quality is ensured by requiring \( \chi^2/\text{ndf} (\chi^2 \text{ per degree of freedom}) < 4 \) for a track fit. The candidates must also have \( \chi^2/\text{IP} \) with respect to any primary interaction greater than 16, where \( \chi^2/\text{IP} \) is defined as the difference in \( \chi^2 \) of a given PV reconstructed with and without the considered track. These \( \mu^+\mu^- \) pairs are required to have an invariant mass of less than 5050 MeV/c² and to be consistent with originating from a common vertex (\( \chi^2_{\text{SV}}/\text{ndf} < 9 \)).

Candidate \( \Lambda \) decays are reconstructed in the \( \Lambda \rightarrow \pi^+\pi^- \) mode from two oppositely-charged particles that either both originate within the acceptance of the VELO (“long \( \Lambda \)” candidates), or both originate outside the acceptance of the VELO (“downstream \( \Lambda \)” candidates). Tracks are required to have \( p_T > 0.5 \) GeV/c, and \( \Lambda \) candidates must have \( \chi^2_{\text{SV}}/\text{ndf} < 30 \) (<25 for downstream \( \Lambda \) candidates), a decay time of at least 2 ps, and a reconstructed invariant mass within 30 MeV/c² of the world average value [30]. Due to the distinct kinematics and topology of the \( \Lambda \) decay, it is not necessary to impose particle identification requirements on the decay products of the \( \Lambda \) candidate.

Candidate \( \Lambda^0 \) decays are formed by combining \( \Lambda \) and dimuon candidates that originate from a common vertex (\( \chi^2_{\text{SV}}/\text{ndf} < 8 \)), have \( \chi^2/\text{IP} < 9 \), \( \chi^2_{\text{SV}} > 100 \) and an invariant mass in the interval 4.9–7.0 GeV/c². The \( \chi^2_{\text{IP}} \) is defined as the difference in \( \chi^2 \) between fits in which the \( \Lambda^0 \) decay vertex is assumed to coincide with the PV and allowing the decay vertex to be distinct from the PV. Candidates must also point to the associated PV by requiring the angle between the \( \Lambda^0 \) momentum vector and the vector between the PV and the \( \Lambda^0 \) decay vertex is less than 8 mrad. The associated PV is the one relative to which the \( \Lambda^0 \) candidate has the lowest \( \chi^2_{\text{IP}} \) value.

The final selection is based on a neural network classifier [31, 32] with 15 variables as input. The single most important variable is the \( \chi^2 \) from a kinematic fit [33] that constrains the decay products of the \( \Lambda^0 \), the \( \Lambda \) and the dimuon system to originate from their respective vertices. Other variables that contribute significantly are the momentum and transverse momentum of the \( \Lambda^0 \) candidate, the \( \chi^2_{\text{SV}} \) and track \( \chi^2/\text{ndf} \) for both muons, the \( \chi^2_{\text{IP}} \) of the \( \Lambda^0 \) candidate, and the separation of the \( \Lambda \) and \( \Lambda^0 \) vertices. Downstream and long \( \Lambda \) decays have separate inputs to the neural network for \( \chi^2_{\text{IP}} \) and \( \chi^2_{\text{SV}} \) because of the differing track resolution and kinematics. In the final selection of \( \Lambda^0 \rightarrow J/\psi \Lambda \) candidates, the \( \mu^+\mu^- \) invariant mass is required to be in the interval 3030–3150 MeV/c². The signal sample used to train the neural network consists of simulated \( \Lambda^0 \rightarrow \mu^+\mu^- \) events, while background is taken from data in the upper sideband of the \( \Lambda^0 \) candidate mass spectrum, between 6.0 and 7.0 GeV/c², which is dominated by candidates with dimuon mass in the \( J/\psi \) region. The requirement on the output of the neural network is chosen to maximise \( N_S/\sqrt{N_S + N_B} \), where \( N_S \) and \( N_B \) are the expected numbers of signal and background events, respectively. To ensure an appropriate normalisation of \( N_S \), the number of \( \Lambda^0 \rightarrow J/\psi \Lambda \) candidates after the preselection is scaled by the measured ratio of branching fractions between the \( \Lambda^0 \rightarrow \mu^+\mu^- \) and \( \Lambda^0 \rightarrow J/\psi \Lambda \) decays [16], and the \( J/\psi \rightarrow \mu^+\mu^- \) branching fraction [30]. The value of \( N_B \) is derived from the background training sample normalised to the number of candidates in the signal region after preselection. The \( \Lambda^0 \rightarrow \mu^+\mu^- \) signal candidates exclude the \( q^2 \) regions of 8.68–10.09 GeV/c⁴ and 12.86–14.18 GeV/c⁴, which are dominated by contributions from the \( J/\psi \) and \( \psi(2S) \) resonances, respectively. The effect of finite \( q^2 \) resolution is negligible. Relative to the preselected event sample, the neural network retains (76.0±0.3)% of the rare decay signal while rejecting (95.9±0.2)% of the background.

4. Peaking backgrounds

Backgrounds are studied using simulated samples of b hadrons in which the final state includes two muons. For the \( \Lambda^0 \rightarrow J/\psi \Lambda \) channel, the only significant contribution found is from \( b^0 \rightarrow J/\psi K_S^0 \) decays, with \( K_S^0 \rightarrow \pi^-\pi^+ \), which has the same topology as the \( \Lambda^0 \rightarrow J/\psi \Lambda \) mode. This contribution leads to a broad shape that peaks below the \( \Lambda^0 \) mass region and is accommodated in the mass fit described later.

For the \( \Lambda^0 \rightarrow \Lambda K^+\pi^- \) channel, sources of peaking background are considered in the \( q^2 \) ranges of interest. The contributions identified are \( \Lambda^0 \rightarrow J/\psi \Lambda \) decays in which an energetic photon is radiated from either of the muons, and \( b^0 \rightarrow K^0_S \mu^+\mu^- \) decays, where \( K_S^0 \rightarrow \pi^-\pi^+ \) and a pion is misreconstructed as a proton. The \( \Lambda^0 \rightarrow J/\psi \Lambda \) decays contribute in the \( q^2 \) region just below \( m_{J/\psi} \), and populate a mass region significantly below the \( \Lambda^0 \) mass. The contribution from the \( b^0 \rightarrow K^0_S \mu^+\mu^- \) decays is estimated by taking the number of \( b^0 \rightarrow J/\psi K^0_S \) events found in the \( \Lambda^0 \rightarrow J/\psi \Lambda \) fit, and scaling this by the ratio of world average
branching fractions between the decay processes $B^0 \to K_S^0 \mu^+ \mu^-$ and $B^0 \to J/\psi K_S^0$ (including the $J/\psi \to \mu^+ \mu^-$ branching fraction) [30]. This gives fewer than 10 events integrated over $q^2$, which is small relative to the expected total background levels.

5. Yields

5.1. Fit description

The yields of signal and background events in the data are determined in the mass range 5.35–5.85 GeV/c$^2$ using unbinned, extended maximum likelihood fits, for the $A^0 \to \Lambda \mu^+ \mu^-$ and the $A^0_2 \to J/\psi \Lambda$ modes. The likelihood function has the form

$$
\mathcal{L} = e^{-(N_1 + N_2 + N_3)} \prod_{i=1}^{N} \left[ N_1 P_1(m_i) + N_2 P_2(m_i) + N_3 P_3(m_i) \right],
$$

where $N_1$, $N_2$, and $N_3$ are number of signal, combinatorial and peaking background events, respectively, and $P_j(m_i)$ are the corresponding probability density functions (PDFs). The mass of the $A^0$ candidate, $m_i$, is determined by a kinematic fit of the full decay chain in which the proton and pion are constrained such that the $p\pi^-$ invariant mass corresponds to the $\Lambda$ baryon mass [30].

The signal shape, in both $A^0 \to \Lambda \mu^+ \mu^-$ and $A^0_2 \to J/\psi \Lambda$ modes, is described by the sum of two Gaussian functions that share a common mean but have independent widths. The combinatorial background is parametrised by a first-order polynomial, while the background due to $B^0 \to J/\psi K_S^0$ decays is modelled by an exponential function (with a cut-off) convolved with a Gaussian function.

For the $A^0 \to J/\psi \Lambda$ mode, the widths and common mean in the signal parametrisation are free parameters. The contribution of the narrower Gaussian function is fixed to be 86% of the total yield based on studies with simulated data. The parameters describing the shape of the peaking background are fixed to those derived from simulated $B^0 \to J/\psi K_S^0$ decays.

For the $A^0_2 \to \Lambda \mu^+ \mu^-$ decay, the signal shape parameters are fixed according to the result of the fit to $A^0 \to J/\psi \Lambda$ data. Studies with simulated data show that the signal shape parameters in both decay modes are consistent with one another, the only deviations being in the tails of the mass distribution. These are due to small differences in the momentum spectra of the muons and energy loss from radiative effects, and are negligible given the uncertainties inherent in the size of the current data sample. The peaking background is found to be negligible in the $q^2$ regions considered and is therefore excluded from the fit.

5.2. Fit results

The invariant mass distributions of the $A^0 \to J/\psi \Lambda$ candidates is shown in Fig. 1. The fitted function provides a good description of the data, with a $\chi^2/\text{ndf}$ corresponding to a probability of 47%. The numbers of signal, combinatorial background and peaking background events are found to be 2680 ± 64, 1294 ± 83 and 1501 ± 83, respectively, and the widths of the Gaussian functions are 16.0 ± 0.4 and 33 ± 5 MeV/c$^2$, compatible with simulation.

The invariant mass distribution for the $A^0_2 \to \Lambda \mu^+ \mu^-$ process, integrated over $q^2$ and in six $q^2$ intervals, are shown in Figs. 2 and 3, respectively. The yields, both integrated and differential in $q^2$, are summarised in Table 1. The same $q^2$ intervals as in Ref. [16] are used to facilitate comparison with the CDF measurements. The statistical significance of the observed signal yields in Table 1 are evaluated as $\sqrt{2\Delta \ln \mathcal{L}}$, where $\Delta \ln \mathcal{L}$ is the change in the logarithm of the likelihood function when the signal component is excluded from the fit, relative to the nominal fit in which it is present. Significant signal yields are only apparent for $q^2 > m_{J/\psi}^2$. Yields at lower-$q^2$ values are compatible with zero, consistent with previous observations [16].

6. Efficiency

The measurement of the differential branching fraction of $A^0_2 \to \Lambda \mu^+ \mu^-$ relative to $A^0 \to J/\psi \Lambda$ benefits from the cancelation of several potential sources of systematic uncertainty in the ratio of efficiencies, $\varepsilon_{\text{rel}} = \varepsilon_{\text{tot}}(A^0_2 \to \Lambda \mu^+ \mu^-)/\varepsilon_{\text{tot}}(A^0 \to J/\psi \Lambda)$. The efficiency for each of the decays is calculated according to

$$
\varepsilon_{\text{tot}} = \varepsilon(\text{geometry})\varepsilon(\text{selection})\varepsilon(\text{geometry}) \times \varepsilon(\text{trigger}(\text{selection})),
$$

where the first term represents the efficiency for the final state particles to be within the LHCb angular acceptance, the second term the combined efficiency for candidate detection, reconstruction and selection, and the rightmost term the efficiency for an event to satisfy the trigger requirements if it is reconstructed and selected. All efficiencies are evaluated using simulated data. A phase space model is used for $A^0 \to J/\psi \Lambda$ decays. The model
based on Refs. [35,36]. Interference effects from charmonium con-
dence as described in Ref. [34], together with Wilson coefficients
$q$ in the lowest
larger-
each

The rise in relative efficiency as a func-
tion of $q^2$ is dominated by two effects. Firstly, at low $q^2$
the muons have lower momenta and therefore have a lower proba-
bility of satisfying the trigger requirements. Secondly, at low $q^2$

A baryon has a larger fraction of the $A_b^0$ momentum and is more
likely to decay outside of the acceptance. The uncertainties com-
bine both statistical and systematic contributions (with the latter
dominating) and include a small correlated uncertainty due to the
use of a single sample of $A_b^0 \to J/\psi \Lambda$ decays as the normalisa-
tion channel for all $q^2$ intervals. The systematic uncertainties are
described in more detail in Section 7.

7. Systematic uncertainties

7.1. Yields

Three separate sources of systematic uncertainty on the mea-
sured yields are considered for both the $A_b^0 \to J/\psi \Lambda$ and $A_b^0 \to
$
tion of the background PDF and the choice of the fixed parameters used in the fits to data.

For the $A_0^b \rightarrow J/\psi \Lambda$ decays, the default signal PDF is replaced by a single Gaussian function. A 2.0% change in signal yield relative to the default fit is observed and assigned as the systematic uncertainty. The shape of the combinatorial background function is changed from the default first-order polynomial to a second-order polynomial. The 1.8% change in the signal yield is assigned as the systematic uncertainty. To estimate the sensitivity of the background process $B^0 \rightarrow J/\psi K_S^0$ to differences between data and simulation, the shape of this background is varied in the fit. A relative uncertainty of 4.7% is assigned. For $A_0^b \rightarrow \Lambda \mu^+ \mu^-$ decays, as the parameter values of the signal PDF are from fits to the $A_0^b \rightarrow J/\psi \Lambda$ data, the uncertainty in the signal shape is accounted for by using the signal shape parameters and covariance matrix obtained from the $A_0^b \rightarrow J/\psi \Lambda$ mass fit. The dependence on the shape of the signal PDF is investigated by fitting data using the parameters determined from the single-Gaussian function treatment of the $A_0^b \rightarrow J/\psi \Lambda$ data described above. The combinatorial background modelling is studied in the same way as for the $A_0^b \rightarrow J/\psi \Lambda$ decays. The systematic uncertainties on the yield in each $q^2$ interval are summarised in Table 3, where the total is the sum in quadrature of the three individual components. No additional uncertainty is assigned to account for finite peaking background, as constraining it to the prediction from simulated $B^0 \rightarrow K_S^0 \mu^+ \mu^-$ decays has a negligible effect.

7.2. Relative efficiencies

In measuring the $q^2$ dependence of the differential branching fraction, three types of correlation are taken into account: those between the normalisation and signal decays; those between the different $q^2$ regions; and those between the geometric, selection and trigger efficiencies. For simplicity, correlations among $q^2$ intervals are taken into account where a systematic uncertainty is significant and neglected where a given uncertainty is small compared to the dominant sources. Overall, the dominant systematic effect identified is that related to the current knowledge of the angular structure of the decays and $q^2$ dependence of the decay channels. The uncertainty due to the finite size of simulated samples used is comparable to that from other sources considered, and is summarised together with all other contributions to the relative efficiency in Table 4, where the total is the sum in quadrature of the individual components.

7.2.1. Decay structure and production polarisation

The main factors that affect the detection efficiencies are the angular structure of the decays and the production polarisation. Although these arise from different parts of the process, the efficiencies are linked and therefore are treated together.

For the $A_0^b \rightarrow \Lambda \mu^+ \mu^-$ decay, the impact of the limited knowledge of the production polarisation, $P_b$, is estimated by comparing the default efficiency with that in either of the fully polarised scenarios, $P_b = \pm 1$, taking the larger difference as the associated uncertainty. To assess the systematic uncertainty due to the decay structure, the efficiency from the default model [34–36] is compared with that from the phase space decay, taking the larger of this difference or the statistical precision as the systematic uncertainty.

For the $A_0^b \rightarrow J/\psi \Lambda$ mode, the default phase space decay is compared with the efficiency derived using the model from Ref. [37], which depends on the polarisation parameter $P_b$ and four complex amplitudes. While fixing $P_b = 0$, a scan of the four complex amplitudes is made and the distribution of the change in efficiency relative to the default is constructed. The sum in quadrature of the mean and r.m.s. of this distribution is assigned as the systematic uncertainty due to the decay structure.

To assess the importance of the production polarisation, this exercise is repeated while setting $P_b = \pm 1$. The sum in quadrature of the mean and r.m.s. of the distribution of deviations from the default gives the combined effect of decay structure and production polarisation. The systematic uncertainty due to production polarisation alone is determined by subtracting in quadrature the systematic uncertainty due to the decay structure.

The impact of $P_b$ on the efficiencies is found to be small using the fully polarised scenarios, which are a conservative variation relative to the recent measurement of Ref. [38].

7.2.2. Lifetime of $A_0^b$ baryon

The $A_0^b$ baryon lifetime used throughout is 1.425 ps [30] and the systematic uncertainty associated with this assumption is investigated by varying the lifetime by one standard deviation (0.032 ps). No significant effect is found.

7.2.3. Reconstruction efficiency for $\Lambda$ baryon

The $\Lambda$ baryon is reconstructed from either long or downstream tracks, and their relative proportions differ between data and simulation. For simulated $A_0^b \rightarrow J/\psi \Lambda$ decays, $21.1 \pm 0.2$% of $\Lambda$ baryon candidates are reconstructed from long tracks, compared to $26.4 \pm 0.7$% in data. For the phase space decay distribution of simulated $A_0^b \rightarrow \Lambda \mu^+ \mu^-$ decays, $21.5 \pm 0.1$% (integrated over $q^2$) are long tracks, indicating that both decay modes have a similar behaviour. To account for a potential effect due to the different fractions of long and downstream tracks observed in data and simulation, the efficiencies are first determined separately for $\Lambda$ baryon candidates formed exclusively from long and from downstream tracks. A new relative efficiency is then determined, setting the fraction of downstream tracks to 27% for simulated $A_0^b \rightarrow J/\psi \Lambda$ decays, and increasing it by 5% in each $q^2$ interval for simulated $A_0^b \rightarrow \Lambda \mu^+ \mu^-$ decays. The systematic uncertainty from this source is assigned as the difference between this reweighted efficiency and the default case.

7.2.4. Production kinematics

There is a small difference between data and simulation in the momentum and transverse momentum distributions of the $\Lambda$ baryon produced in the $A_0^b \rightarrow J/\psi \Lambda$ decays. Simulated data are reweighted to reproduce these distributions in data, and the differences in the relative efficiencies with respect to the default are

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**Table 3**

Absolute systematic uncertainties on the yields for the $A_0^b \rightarrow \Lambda \mu^+ \mu^-$ decay.

| Source                  | $q^2$ interval [GeV$^2$/c$^4$] | 0.00–2.00 | 2.00–4.30 | 4.30–6.88 | 10.09–12.86 | 14.18–16.00 | 16.00–20.30 |
|-------------------------|-------------------------------|-----------|-----------|-----------|-------------|-------------|-------------|
| Signal PDF              |                               | 0.08      | 0.08      | 0.16      | 0.4         | 0.08        | 2.3         |
| Combinatorial background|                               | 2.7       | 0.7       | 0.21      | 3.5         | 2.2         | 2.5         |
| Signal shape parameters |                               | 0.04      | 0.08      | 0.09      | 0.4         | 0.17        | 1.1         |
| Total                   |                               | 2.7       | 0.7       | 0.28      | 3.5         | 2.2         | 3.5         |
is due to differences between reweighted neural network input variables.

The relative differential branching fraction is measured in each $q^2$ interval as

$$\frac{1}{B(A_b^0 \rightarrow J/\psi \Lambda)} \frac{dB(A_b^0 \rightarrow A \mu^+ \mu^-)/dq^2}{dq^2} = \frac{N_S(A_b^0 \rightarrow A \mu^+ \mu^-)}{N_S(A_b^0 \rightarrow J/\psi \Lambda)} \frac{1}{\varepsilon_{\text{rel}}} B(J/\psi \rightarrow \mu^+ \mu^-) \frac{1}{\Delta q^2}, \quad (3)$$

where $\Delta q^2$ represents the width of the given $q^2$ interval.

For $q^2$ regions in which no statistically significant signal is observed, an upper limit on $dB(A_b^0 \rightarrow A \mu^+ \mu^-)/dq^2$ is calculated using the following Bayesian approach. The signal PDF for $A_b^0 \rightarrow A \mu^+ \mu^-$ decays is reparametrised in terms of the relative differential rate of Eq. (3), $N_S(A_b^0 \rightarrow J/\psi \Lambda)$, $\varepsilon_{\text{rel}}$ and $B(J/\psi \rightarrow \mu^+ \mu^-)$.

The known uncertainties on the $A_b^0 \rightarrow J/\psi \Lambda$ yield and $\varepsilon_{\text{rel}}$ are included in the fit with Gaussian constraints and the profile likelihood over the relative branching fraction is then obtained. An upper limit is set at the value where the posterior likelihood corresponds to 90% (95%). A uniform prior between zero and 3 $\times$ 10^{-3} is used. The limits on the absolute differential branching fractions are given by the product of the relative limit and $B(A_b^0 \rightarrow J/\psi \Lambda)$ and include the uncertainty on $B(A_b^0 \rightarrow J/\psi \Lambda)$ from Ref. [30].

The measured relative differential branching fraction is presented in Table 5, while the absolute differential branching fraction is given in Table 6 and shown in Fig. 4. The integrated relative branching fraction is obtained as the sum of the differential rates in six $q^2$ intervals (weighted by $\Delta q^2$). This gives the integral over the full phase space, with the exception of the $q^2$ regions corresponding to the $J/\psi$ and $\psi(2S)$ resonances. In this integration the statistical uncertainties are added in quadrature. Systematic uncertainties on the $A_b^0 \rightarrow A \mu^+ \mu^-$ yield and the relative efficiency are treated as uncorrelated. The remaining systematic uncertainties, including the statistical and systematic uncertainties in the normalisation mode yield from Ref. [30], are treated as fully correlated. This leads to the relative branching fraction of $B(A_b^0 \rightarrow A \mu^+ \mu^-)$

$$\frac{B(A_b^0 \rightarrow J/\psi \Lambda)}{B(A_b^0 \rightarrow J/\psi \Lambda)} = (1.54 \pm 0.30(\text{stat}) \pm 0.20(\text{syst}) \pm 0.02(\text{norm})) \times 10^{-3},$$

which corresponds to the absolute branching fraction.
$B(Λ_b^0 → Λμ^+μ^-)$

\[
B(Λ_b^0 → Λμ^+μ^-) = (0.96 ± 0.16(\text{stat}) ± 0.13(\text{syst}) ± 0.21(\text{norm})) \times 10^{-6},
\]

where the last uncertainty accounts for the branching fraction of the normalisation mode [30].

These new measurements of the branching fraction and differential branching fraction for the rare decay $Λ_b^0 → Λμ^+μ^-$ are based on a yield of $78 ± 12$ signal decays obtained from data, corresponding to an integrated luminosity of 1.0 fb$^{-1}$, collected at a centre-of-mass energy of 7 TeV. Evidence for this process is found for $q^2 > m_{J/ψ}^2$ and is compatible with previous measurements by the CDF Collaboration [16]. Within the precision of measurements presented in this Letter, the Standard Model predictions of Ref. [14] provide a good description of the data.

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