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Observation of the rare decay $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$

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Summary. — The decay mode $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ is a $b \to d$ flavour changing neutral current transition and can therefore only occur at loop level in the Standard Model. In new physics models, new heavy particles can contribute and can significantly change the branching fraction of this process. The recent first observation of the decay mode $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ by the LHCb experiment represents the first observation of a $b \to d$ transition in the baryon sector. In these proceedings the aforementioned LHCb analysis will be outlined and the branching fraction measurement of $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ presented.

1. – Introduction

The decay of the Λ_b^0 baryon into the $p\pi^-\mu^+\mu^-$ final state, where the muons do not originate from a hadronic resonance, is mediated by a $b \to d$ transition. Such decays are highly suppressed in the Standard Model (SM), as the leading order amplitudes are described by loop diagrams and are also suppressed by the relevant Cabibbo-Kobayshi-Maskawa (CKM) factors. This suppression is not necessarily present in extensions to the SM, and such decays are therefore sensitive to contributions from new particles. One of the lowest-order diagrams for the decay(1) $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ is shown in fig. 1.

Together with the relevant form factors, the measurement of the $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ branching fraction [1] with respect to that of the analogous $b \to s$ transition $\Lambda_b^0 \to pK^-\mu^+\mu^-$, allows the ratio of CKM elements $|V_{td}|/|V_{ts}|$ to be determined. Comparing the value of $|V_{td}|/|V_{ts}|$ from these processes with that measured via mixing processes would test the Minimal Flavour Violation hypothesis [2-4]. The decay $\Lambda_b^0 \to pK^-\mu^+\mu^-$ has recently been observed for the first time by the LHCb Collaboration [5].

At present, no form-factor calculations have been made for the $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ and $\Lambda_b^0 \to pK^-\mu^+\mu^-$ channels due to the complicated hadronic structure in the proton-meson systems. However, recent advances in lattice calculations [6] could make this possible in the future.

(1) The inclusion of charge-conjugate processes is implied throughout these proceedings.

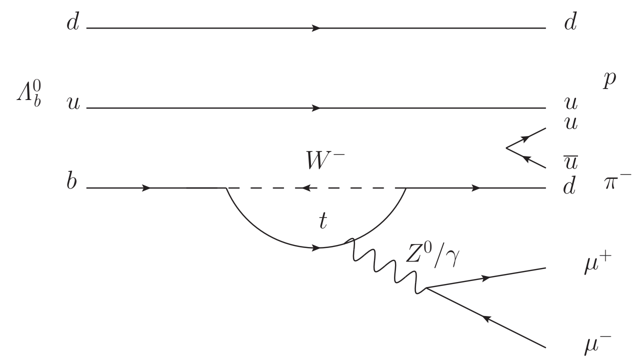

Fig. 1. – One of the lowest-order diagrams for the decay $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$.

These proceedings describe the first observation of the decay $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$, using proton-proton collision data corresponding to an integrated luminosity of 3 fb^{-1}. The data were collected with the LHCb experiment at centre-of-mass energies of 7 and 8 TeV. The branching fraction is determined relative to that of the tree-level decay, $\Lambda_b^0 \to J/\psi(\to \mu^+\mu^-)p\pi^-$, denoted as $\Lambda_b^0 \to J/\psi\, p\, \pi^-$ hereafter, which has been measured with a precision of 15% [7,8].

The LHCb detector [9,10] 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 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 of the magnet. The tracking system provides a measurement of the momentum of charged particles with a relative uncertainty that varies from 0.5% at low momentum to 1.0% at 200 GeV/c. The minimum distance of a track to a primary vertex (PV), the impact parameter, is measured with a resolution of $(15+29/p_{\mathrm{T}})\mu$m, where p_{T} is the component of the momentum transverse to the beam, in GeV/c.

Different types of charged hadrons are distinguished using information from two Ring-Imaging Cherenkov (RICH) detectors. Muons are identified by a system composed of alternating layers of iron and multiwire proportional chambers. The online event selection is performed by a trigger [11], which 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.

2. – Analysis strategy and selection

The $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ branching fraction, as measured relative to $\mathcal{B}(\Lambda_b^0 \to J/\psi\, p\, \pi^-)$, can be given by the expression

$$(1) \qquad \mathcal{B}_{\Lambda_b^0\to p\pi^-\mu^+\mu^-} = \mathcal{B}_{\Lambda_b^0\to J/\psi\, p\,\pi^-}\mathcal{B}_{J/\psi\to\mu^+\mu^-}\frac{N_{\Lambda_b^0\to p\pi^-\mu^+\mu^-}}{N_{\Lambda_b^0\to J/\psi(\to\mu^+\mu^-)p\pi^-}}\frac{\epsilon_{\Lambda_b^0\to J/\psi\, p\,\pi^-}}{\epsilon_{\Lambda_b^0\to p\pi^-\mu^+\mu^-}},$$

where $N(X)$ is the yield of the final state X and $\varepsilon(X)$ is the efficiency to select that final state. The efficiencies are obtained from simulated events and specific control samples in data. Since the normalisation channel $\Lambda_b^0 \to J/\psi\, p\, \pi^-$ has the same final state and similar kinematics as the signal decay, many systematic uncertainties cancel in the efficiency ratio.

Given that very few events are expected ($\sim$ 10–20), an efficient and effective selection is vital to increase the chances of observing the decay. The selection was optimised using the normalisation channel in data and simulation, and the analysis is heavily reliant on machine learning based methods to help distinguish signal from background.

The selection for the normalisation and signal channels is identical, save for the requirement on the square of the dimuon invariant mass, q^2. For the signal channel the regions in q^2 corresponding to the J/ψ and $\psi(2S)$ resonances are excluded, whereas for the normalisation channel a cut of ± 60 Mev/c^2 is placed around the J/ψ mass.

3. – Mass fits and backgrounds

The shape of the $\Lambda_b^0 \to J/\psi\, p\, \pi^-$ mass distribution is described by the sum of two Gaussian functions with power law tails and a shared mean, where the Gaussian parameters are allowed to vary in the fit and the tail parameters are obtained from the simulation. Combinatorial background (*i.e.*, background where a set of tracks are incorrectly assumed to all come from the same mother particle) is parametrised with an exponential function with a decay constant that is allowed to vary in the fit. Finally, there is a small contribution from the decay $\Lambda_b^0 \to J/\psi p K^-$, the shape of which is determined from the simulation and included in the fit to the data. The yield of the normalisation channel is obtained by performing an extended unbinned maximum likelihood fit to the $\Lambda_b^0 \to J/\psi\, p\, \pi^-$ mass distribution, as shown in fig. 2.

In total, 1017 ± 41 $\Lambda_b^0 \to J/\psi\, p\, \pi^-$ candidates are observed. This yield is significantly lower than in refs. [8, 12], owing to the tighter selection employed to search for the $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ decay.

The signal shape is determined from the fit to the normalisation decay mode in data, with corrections to account for the differences between the signal and normalisation modes obtained from the simulation. The combinatorial background is parameterised as in the fit for the normalisation mode. There is a remaining partially reconstructed background component (*i.e.*, a background where one or more tracks have not been reconstructed) in the signal mode, which arises from Λ_c^+ cascade decays. In these decays the muons cannot come from a J/ψ, hence this background is negligible in the normalisation channel. The shape for this background is taken from $\Lambda_b^0 \to pK^-\mu^+\mu^-$ data. The fit to the $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ mass distribution is shown in fig. 3.

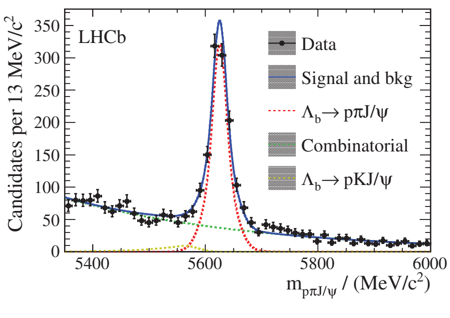

Fig. 2. – Mass distribution of $\Lambda_b^0 \to J/\psi\, p\, \pi^-$ candidates compared to the result of the fit. The fit parametrisation is described in the text.

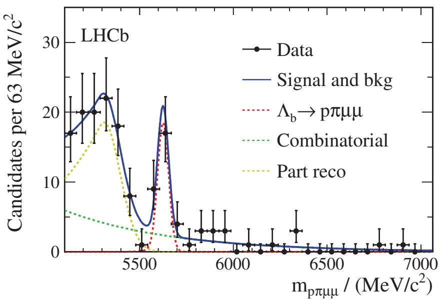

Fig. 3. – Mass distribution of $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ candidates compared to the result of the fit. The fit parameterisation is described in the text.

4. – Results

In total, 22 ± 6 $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ candidates are observed. This corresponds to a significance of 5.5σ. The branching fraction relative to the normalisation mode is measured to be

$$\frac{\mathcal{B}(\Lambda_b^0 \to p\pi^-\mu^+\mu^-)}{\mathcal{B}(\Lambda_b^0 \to J/\psi(\to \mu^+\mu^-)p\pi^-)} = 0.044 \pm 0.012 \pm 0.007, \tag{2}$$

and the absolute branching fraction is measured to be

$$\mathcal{B}(\Lambda_b^0 \to p\pi^-\mu^+\mu^-) = (6.9 \pm 1.9 \pm 1.1^{+1.3}_{-1.0}) \times 10^{-8}, \tag{3}$$

where in both cases the first uncertainty is statistical and the second is systematic. The dominating systematic certainty arise from the error associated with the modelling of the q^2 and dihadron mass spectrum.

The distributions in q^2 and the dihadron mass for events falling within the $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ signal window are shown in fig. 4.

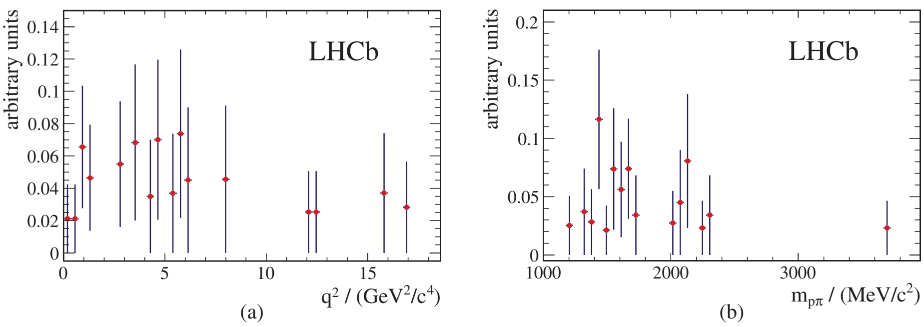

Fig. 4. – The distributions in q^2, (a), and the dihadron mass, (b), for events falling within the $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ signal window.

5. – Summary

These proceedings discussed the search for, and first observation of, the rare decay $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$. The analysis was performed with proton-proton collision data collected with the LHCb experiment corresponding to 3 fb^{-1} of integrated luminosity. The search is made excluding the J/ψ and $\psi(2S)$ resonances. A signal is observed with a significance of 5.5 standard deviations, which constitutes the first observation of a $b \to d$ transition in a baryonic decay.

With further advances in lattice QCD, combined with the branching fraction measurement of $\Lambda_b^0 \to pK^-\mu^+\mu^-$, this result will allow $|V_{td}|/|V_{ts}|$ to be measured, enabling a test of the Minimal Flavour Violation hypothesis.

REFERENCES

[1] The LHCb Collaboration, *JHEP*, **04** (2017) 029.
[2] Buras A. J. *et al.*, *Phys. Rev. B*, **500** (2001) 161.
[3] Feldmann T. and Mannel T., *JHEP*, **02** (2007) 067.
[4] The LHCb Collaboration, *JHEP*, **10** (2015) 034.
[5] The LHCb Collaboration, arXiv:1703.00256.
[6] Wilson D. J., *Phys. Rev D*, **92** (2015) 094502.
[7] The LHCb Collaboration, *Chin. Phys. C*, **40** (2016) 011001.
[8] The LHCb Collaboration, *JHEP*, **07** (2014) 103.
[9] The LHCb Collaboration, *JINST*, **3** (2008) S08005.
[10] The LHCb Collaboration, *Int. J. Mod. Phys. A*, **30** (2015) 1530022.
[11] Aaji R. *et al.*, *JINST*, **8** (2013) P04022.
[12] The LHCb Collaboration, *Phys. Rev. Lett.*, **117** (2016) 082003.