$\Lambda_c^+ \to p\mu^+\mu^-$ RESULTS FROM LHCb*

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The search for rare decay $\Lambda_c^+ \to p\mu^+\mu^-$ with LHCb data corresponding to an integrated luminosity of 3.0 fb^{-1} is presented. Such decays are highly suppressed in Standard Model and they are sensitive to contributions from new physics phenomena. No significant signal is observed. Using $\Lambda_c \to p\phi$ decay as normalization channel, an upper limit on branching fraction of $B(\Lambda_c^+ \to p\mu^+\mu^-) < 7.7\ (9.6) \times 10^{-8}$ at 90% (95%) C.L. is set. The first observation of $\Lambda_c^+ \to p\omega$ is also reported.

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1. Introduction

The class of processes mediated by Flavor Changing Neutral Currents (FCNC) plays an important role in searches for new physics. Such processes cannot occur at leading order (tree level), only at second order involving loop diagrams where contributions due to propagation of new particles can modify Standard Model (SM) predictions. The FCNC decay $\Lambda_c^+ \to p\mu^+\mu^-$ (the inclusion of charge-conjugated processes is implied throughout this article) is highly suppressed in the SM due to the Glashow–Iliopoulos–Maiani mechanism [1]. The branching ratios for short-distance contributions to the transition $c \to ul^+l^-$ are expected to be below 10^{-8} in the SM. While reconstruction of very rare decays is often challenging due to very large backgrounds, measurements of such decays afford the opportunity to discover tiny effects of new physics phenomena which may modify SM predictions [2, 3].

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The search for the $\Lambda_c^+ \to p\mu^+\mu^-$ decay has been previously performed by the BaBar Collaboration [4] yielding $11.1 \pm 5.0 \pm 2.5$ events with the upper limit on branching fraction of 4.4×10^{-5} at 90% C.L. The results from the LHCb Collaboration are reported [5]. The LHCb detector and its performance is described in Refs. [6–12].

2. Analysis

The Λ_c^+ baryons are produced in two ways: as prompt Λ_c^+, which originate from the pp collision, or as secondary decays of b hadrons. As the production cross section [13, 14] for $c\bar{c}$ is much higher than for $b\bar{b}$, the main focus is on prompt Λ_cs. The events of $\Lambda_c^+ \to p\mu^+\mu^-$ decay are reconstructed from two oppositely charged tracks identified as muons and a track identified as proton. For the measurement, the three ranges of dimuon mass were defined to separate short-distance and long-distance contributions:

- a nonresonant region ($\Lambda_c^+ \to p\mu^+\mu^-$), with excluded ranges ± 40 MeV/c^2 around the known ω and ϕ masses,
- a region around the known ϕ mass, [985, 1055] MeV/c^2, used as a normalization channel,
- a region around the known ω mass, [759, 805] MeV/c^2, used to isolate the $\Lambda_c^+ \to p\omega$ decay.

After the preselection, the normalization channel is still dominated by combinatorial background; we employ a two stage multivariate analysis to further reduce this background. A boosted decision tree (BDT) method was used as it showed the best performance. In the first stage, the BDT was trained using kinematic and topological variables of Λ_c. For BDT training, the signal is represented by the simulated events while background is taken from data in the sidebands regions outside the signal Λ_c invariant mass region. It is worth to mention that k-folding technique is used to keep full sample for measurement and ensure the training to be unbiased [15]. Relatively loose discrimination was used at this stage to obtain reasonable yield for normalization channel on acceptable background. About 400 candidates were selected (Fig. 1).

The second BDT (BDT-2) was trained using variables from the first BDT and additional variables related to decay products. Final selection is performed in 3 dimensions:

- BDT-2 variable;
- Particle identification variable for muon;
- Particle identification variable for proton.

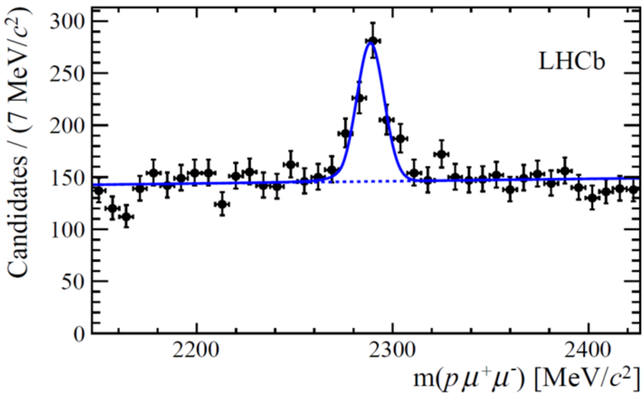

Fig. 1. Mass distribution of $\Lambda_c^+ \to p\mu^+\mu^-$ candidates in the ϕ region after the first BDT requirement.

This procedure determines the optimal set of BDT and particle identification (PID) requirements. The upper limit (calculated in the same way as for the final measurement) was taken as a figure of merit. Optimisation is performed using the Monte Carlo method. A number of toy samples was generated using relevant probability density functions for both signal and background.

3. Results

The results of selection are shown in Fig. 2. As no significant signal for nonresonant region is observed, only an upper limit can be determined. For the normalization channel in ϕ region, 96 ± 11 candidates were selected. In ω region, 13.2 ± 4.3 candidates were found.

In the dimuon invariant mass plot, one can clearly see two peaks at ω and ϕ (Fig. 3). It is worth noting that this is the first observation with 5 standard deviations for the ω region. No sign of ρ contribution is observed.

The systematic uncertainty is taken into account in the upper limit determination procedure (Table I). The main sources are related to finite size of simulation samples which limits the precision of efficiency ratio, residual differences between data and simulation of the BDT distribution and simulation of PID. Other sources of systematic uncertainty were determined to be small and were neglected.

Using $\mathrm{CL_s}$ method [16], the upper limit of branching fraction relative to $\Lambda_c \to p\phi$ was determined to be

$$\frac{B\left(\Lambda_c^+ \to p\mu^+\mu^-\right)}{B\left(\Lambda_c^+ \to p\phi\right) B\left(\phi \to \mu^+\mu^-\right)} < 0.24\ (0.28) \text{ at } 90\%\ (95\%) \text{ C.L.}$$

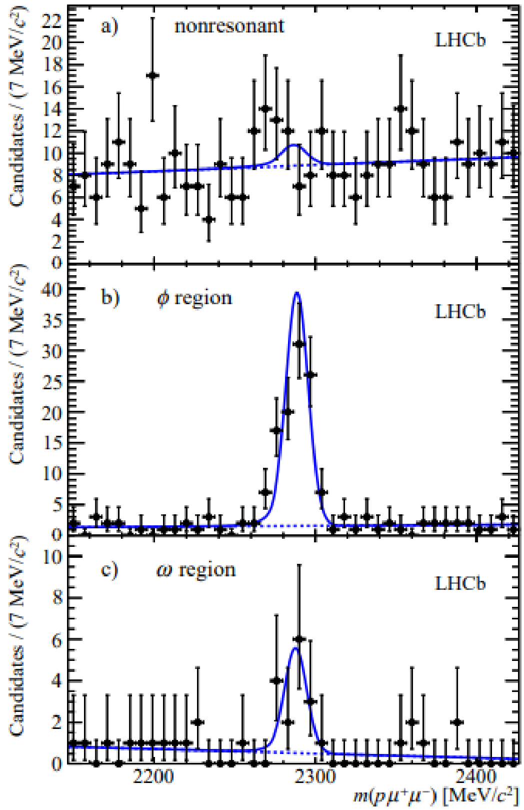

Fig. 2. Mass distribution for selected $p\mu^+\mu^-$ candidates in the three regions of the dimuon invariant mass: (a) nonresonant region, (b) ϕ region, (c) ω region.

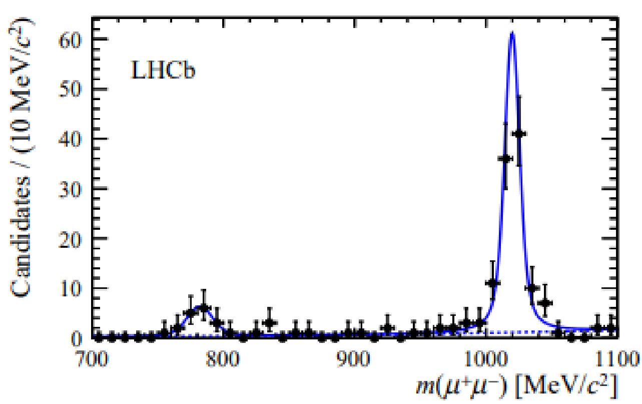

Fig. 3. Invariant mass distribution $m(\mu^+\mu^-)$ for $\Lambda_c^+ \to p\mu^+\mu^-$ candidates with mass ± 25 MeV$/c^2$ around the Λ_c^+ mass.

TABLE I

Systematic uncertainties on the efficiency ratio used in the determination of the branching fraction in the nonresonant and ω regions.

Uncertainty source	Value [%] $\Lambda_c^+ \to p\mu^+\mu^-$ nonresonant	Value [%] $\Lambda_c^+ \to pV(\mu^+\mu^-)$ ω region
Size of simulation samples	4.4	10.0
BDT cut	4.8	4.8
PID cut	0.7	0.7
Total	6.5	11.1

Using values of the branching fractions for $\Lambda_c^+ \to p\phi$ and $\phi \to \mu^+\mu^-$ decays and their statistical uncertainties, an upper limit on the branching fraction (Fig. 4) is determined to be

$$B\left(\Lambda_c^+ \to p\mu^+\mu^-\right) < 7.7\ (9.6) \times 10^{-8} \text{ at } 90\%\ (95\%) \text{ C.L.}$$

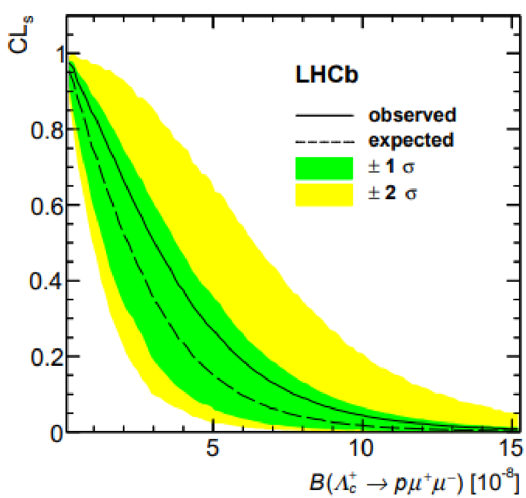

Fig. 4. The CL$_\mathrm{s}$ value as a function of the $B(\Lambda_c^+ \to p\mu^+\mu^-)$ branching fraction.

4. Conclusion

A search for rare decay $\Lambda_c^+ \to p\mu^+\mu^-$ in pp collisions collected by the LHCb experiment is presented. No signal has been found in data corresponding to integrated luminosity of 3.0 fb^{-1}. The upper limit for branching fraction of $B(\Lambda_c^+ \to p\mu^+\mu^-) < 7.7\ (9.6) \times 10^{-8}$ at 90% (95%) C.L. was determined. The improvement by 2 orders of magnitude was achieved with respect to previous measurement. First observation of $\Lambda_c^+ \to p\omega$ decay at 5σ statistical significance is reported.

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