PROCEEDINGS OF SCIENCE

Feasibility of inclusive $B \to \Lambda_c\, X$ branching fraction measurement and search for baryonic *B* meson decays with invisible particles

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We present a feasibility study for a new measurement of inclusive branching fraction of B meson decays into a charmed Λ_c baryon using Belle data set (eventually expanded to Belle II data set). According to a recently proposed model baryonic B meson decays could shed light on some of the big unanswered questions, like the nature of dark matter. Baryonic decays of B mesons are, however, still measured with a poor accuracy. A more precise measurement of inclusive $B \to \Lambda_c$ decay branching fraction could be also useful to gain a better confidence on B meson weak decays treatment.

With help of a newly developed exclusive tagging algorithm, it may be possible to perform a more precise measurement of inclusive $B \to \Lambda_c$ decay branching fraction using Belle data set and eventually improve the measurement expanding it to Belle II data set.

18th International Conference on B-Physics at Frontier Machines - Beauty2019 -
29 September / 4 October, 2019
Ljubljana, Slovenia

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PoS(Beauty2019)063

1. Motivation

The Standard Model of Particle Physics (SM), while now tested to great precision, leaves many questions unanswered. The most striking ones:

- the quest for **dark matter** (DM): gravitationally inferred but thus far undetected component of matter which makes up roughly 26% of the energy budget of the Universe (see [1],[2]).
- the matter-antimatter asymmetry caused by **Baryogenesis** that satisfies the three Sakharov conditions [3]: C and CP Violation (CPV), baryon number violation, and departure from thermal equilibrium. A recent model [4] proposes a new mechanism of Baryogenesis and DM production, in which both the dark matter relic abundance and the baryon asymmetry arise from neutral B mesons oscillations and their subsequent decays, as shown in Fig.1.

  Decays of B mesons into baryons, mesons and missing energy would be a distinct signature of this mechanism that can be searched for at both current and upcoming experiments.

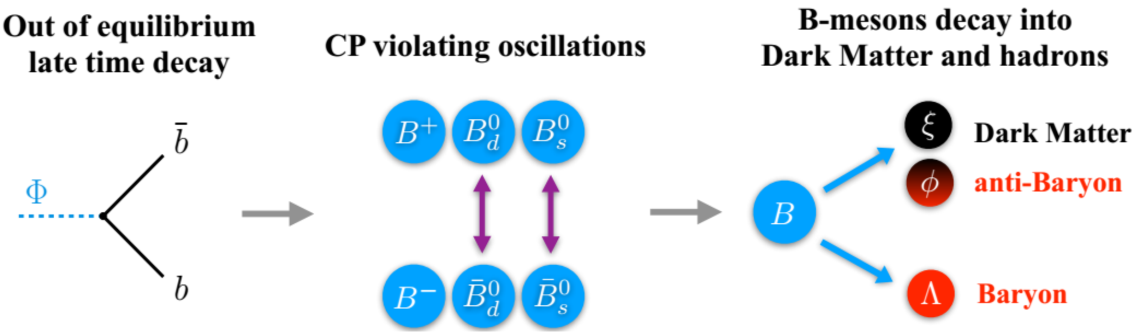

Figure 1: Summary of the mechanism generating the baryon asymmetry and DM relic abundance [4].

Most abundant inclusive B meson baryonic decays are those with a Λ_c baryon in the final state, due to a relatively large $\mid V_{cb} \mid$ element of Cabibbo-Kobayashi-Maskawa matrix. The inclusive branching fractions of $B \to \Lambda_c$ are of the order of a percent (e.g. $\mathscr{B}$ ($B^0 \to \Lambda_c^- X$) = $(5.0^{+2.1}_{-1.5})\%$ [5]). This assures high enough statistics for the measurement. Baryonic decays of B mesons are, as seen from the above example, still measured with a poor accuracy. A more precise measurement of inclusive $B \to \Lambda_c$ decay branching fraction may shed light on the appropriateness of these B decays treatment, particularly of strong interaction effects modelling.

2. B factory

Inclusive B meson baryonic decays can be studied with great precision at **B factories**, electron-positron colliders with the centre of mass energy tuned to the Υ(4S) resonance (decaying $\sim$100% into pairs of B mesons), such as Belle (or Belle II).
The Belle experiment ([6]) at the KEK B collider, operating between 1999 and 2010 in Tsukuba, Japan, collected data corresponding to an integrated luminosity of around 1 ab^{-1}.
At the beginning of the current decade a major upgrade of the KEK B-factory facility was started

and the upgraded detector [7] for Belle II experiment started to operate in 2018. During its running period Belle II is expected to collect about 50 times more data than its predecessor, due to a factor of 40 increase in the luminosity.

3. Experimental method

B factories offer a unique capability to study B decay modes with missing energy. The precisely known center of mass energy, combined with the exclusive reconstruction of the accompanying B meson (denoted as B_{tag}), permits reconstruction of a signal B meson, B_{sig} , even if its decay products can not be detected by the detector (neutrinos, for example).
A new exclusive tagging algorithm, based on machine learning, was developed for Belle II (embedded in the Belle II Analysis Software Framework [8]): **Full Event Interpretation** (FEI)[9]. It constructs plausible B_{tag} meson decay-chains compatible with the observed tracks and clusters, and calculates for each decay-chain its probability for correctly describing the true process. FEI uses either hadronic or semileptonic B meson decay-channels. The decay-chain of the B_{tag} is explicitly reconstructed and therefore the assignment of tracks and clusters to the tag-side and signal-side is known.
Exploiting this method it is possible to set strong kinematic constraints on the B_{sig}. In particular, in the case of the inclusive $B \to \Lambda_c$ decays, one reconstructs Λ_c in the most abundant decay mode ($\Lambda_c \to p\ K\ \pi$) and all the remaining tracks and clusters represent particles produced in the B_{sig} decay. The invariant mass of these B_{sig} decay products can be calculated (missing mass, M_{miss}) even if the latter do not leave any detectable signal in the detector. In case that one finds values of M_{miss} below the proton mass this would be a clear indication of baryon number violation. In addition, also the missing energy in the decay can be measured. A non-zero missing energy points to inivisible particles involved in the process.

4. Expected results

The measurement will be performed using Belle data set, and later - depending on the results as well as the integrated luminosity of Belle II data available at the time - be expanded to Belle II data set.
Results of the study crucially depend on the performance of FEI. This will be carefully studied first, together with a possible effect of increased beam backgrounds in Belle II data. Additional improvements of FEI may be considered, by examination of background energy deposits in the electromagnetic calorimeter and background charged tracks reconstructed in the detector. Estimation of FEI efficiency, indispensable in measurement of any B_{sig} branching fraction, will be performed using simulated Monte Carlo data. Resolution of M^2_{miss} reconstruction will be studied next, to determine how accurately additional decay products of B_{sig} can be identified.
Below, estimates of expected signal yield in Belle data are given:

$$N_{sig}(B^+ \to \Lambda_c^+ X) = N_{B\bar{B}} \cdot \mathscr{B}(B^+ \to \Lambda_c^+ X) \cdot \varepsilon^+_{FEI} \cdot \mathscr{B}(\Lambda_c \to p\ K\ \pi) \cdot \varepsilon_\Lambda \sim 3.7 \cdot 10^3$$

$$N_{sig}(B^+ \to \Lambda_c^- X) = N_{B\bar{B}} \cdot \mathscr{B}(B^+ \to \Lambda_c^- X) \cdot \varepsilon_{FEI}^{+} \cdot \mathscr{B}(\Lambda_c \to p\ K\ \pi) \cdot \varepsilon_\Lambda \sim 8.8 \cdot 10^3$$

$$N_{sig}(B^0 \to \Lambda_c^- X) = N_{B\bar{B}} \cdot \mathscr{B}(B^0 \to \Lambda_c^- X) \cdot \varepsilon_{FEI}^{0} \cdot \mathscr{B}(\Lambda_c \to p\ K\ \pi) \cdot \varepsilon_\Lambda \sim 3.0 \cdot 10^3$$

with $\varepsilon_{FEI}^{+} = 0.76\%$ and $\varepsilon_{FEI}^{0} = 0.46\%$ being maximum tag-side-efficiency of FEI on simulated data from the official Monte Carlo campaign of the Belle experiment, for charged and neutral hadronic tagging, respectively.

$N_{B\bar{B}} = 772 \cdot 10^6$ is the total number of $B\bar{B}$ pairs in the full Belle dataset ($711 fb^{-1}$)

$\varepsilon_\Lambda \sim 50\%$ represents roughly the efficiency of Λ_c reconstruction, assuming on the average 80

Taking into account an estimate of the signal purity of $\sim 1/4$, the expected statistical accuracy of the measurement would be: $[\sigma(N_{sig})/N_{sig}]_{stat} \sim \frac{1}{\sqrt{P \cdot N_{sig}}} \sim 5\%$

5. Conclusions

A feasibility study for a new measurement of the inclusive branching fraction of B meson decays into a charmed Λ_c baryon has been initiated. Such decays can be studied with great precision at B factories, where a large number of B meson pairs are produced. The measurement would exploit a new exclusive tagging algorithm, based on machine learning, to reconstruct decays of B mesons on the tagged side with a considerable efficiency. The signal B meson, B_{sig}, can then be reconstructed, even if its decay products can not be detected by the detector. This technique would also permit the search for invisible particles in such decays, as predicted by a recent model proposing a new mechanism of Baryogenesis and dark matter production.

6. Acknowledgments

The author acknowledges the ARRS (Governamental Slovenian Research Agency) for supporting the author with PhD grant.

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