Search for ALPs with gluon couplings in $B \to Ka(\to \pi^+\pi^-\pi^0)$ at Belle II

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Motivation

Axion-like particles (ALPs) are among the most widely recognized groups of theoretical extensions to the Standard Model (SM). Whilst many of the current collider searches focus on ALPs coupling predominantly to photons or W and Z bosons, this work targets Heavy QCD Axions with dominant coupling to gluons and a mass in the GeV range.

A particularly interesting decay mode is $a \to \pi^+\pi^-\pi^0$ since, for decay constants in the TeV range, it produces a long-lived ALP a. Although large parts of the parameter space have been explored by beam dump experiments and former searches by BaBar and Belle, as shown in Figure 1, the displaced signature of the ALP is expected to offer a promising chance to extend the existing limits.

Analysis Strategy and First Results

This analysis searches for Heavy QCD Axions with masses in the range of 420 to 1000 MeV/c^2 and lifetimes between 10^{-5} and 100 cm in $B^\pm \to K^\pm a$ decays at Belle II. Due to different signatures of long-lived particles in the detector, the event reconstruction and

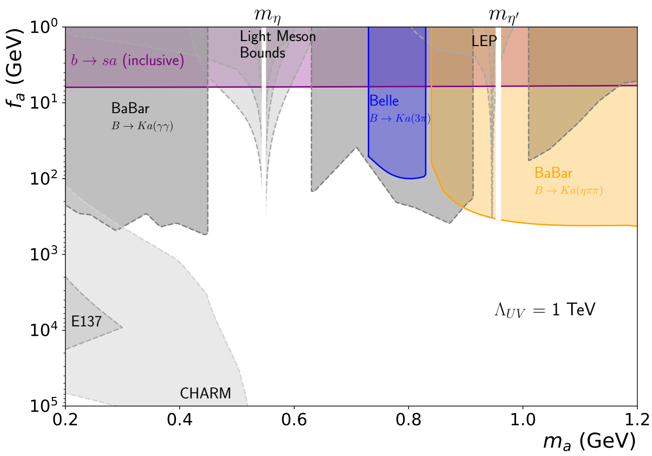

Figure 1: Current status of experimental limits in the m_a-f_a parameter space for Heavy QCD Axions in the GeV region with $\Lambda_{UV} = 1$ TeV.

selection are optimized separately for promptly decaying versus displaced ALPs. Both analyses are then combined in the subsequent sensitivity estimation, based on simulated events, and the final limit extraction.

For the prompt analysis, the dominant background contribution is $e^+e^- \to q\bar{q}$ events with $q = u, d, s, c$, the so-called continuum background. To suppress this background, a dedicated BDT is trained on variables describing the different event topologies for $B\bar{B}$ versus continuum events. After selecting on the output probability of the BDT, expected upper limits on the signal branching fraction are estimated to be of the order of 10^{-6} to 10^{-8}. By comparing the upper limits with predictions from the theory model, model-dependent sensitivity estimates in the mass-decay constant parameter space can be achieved, showing a promising chance to extend existing limits for masses between 460 and 700 MeV/c^2.

The displacement of the ALP poses multiple challenges for the event reconstruction of the long-lived analysis, with the most important one being the worsening of the π^0 mass resolution for increasing ALP lifetime. It can be improved by updating the π^0 kinematics using a decay vertex fit. On the other hand, the displacement of the vertex can be exploited to strongly suppress prompt SM background resulting in estimated upper limits on the signal branching fraction in the order of 10^{-5} to 10^{-7}.

Outlook for PhD

Contrary to expectations, the long-lived analysis is not yet able to extend the model-dependent sensitivity from the prompt analysis towards larger decay constants. Therefore, the selection strategy needs further optimization for different lifetimes. To finalize the analysis, corrections and systematic uncertainties need to be taken into account and the MC/data agreement has to be validated in sideband studies. In addition, a fit-based signal and background extraction should be implemented.