Search for Axion-like particles at the LHCb

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Introduction

Axions and axion-like particles (ALPs) are hypothetical bosons that appear in theoretical extensions to the Standard Model. They represent some of the most popular candidates for Beyond-the-Standard-Model physics, with the QCD axions offering a solution to the strong CP problem, and light ALPs being candidates for dark matter [1,2]. While the current experimental limits on light ALPs are strict, large portions of the heavy-ALP mass-coupling parameter space remain unexplored [3].

The aim of this project was to search for heavy ALPs produced in particle collisions. The data from the LHCb experiment was used to look for ALPs generated in rare B-meson decays, making the search sensitive to ALP masses up to approximately 4.4 GeV.

Methodology

Decay Channel

The search for ALPs (a) focused on B^0 meson decays into $K^{*0}(892)$ according to: [4]

$$B^0 \to K^{*0} a$$
$$K^{*0} \to K^+ \pi^-$$
$$a \to \gamma\gamma$$

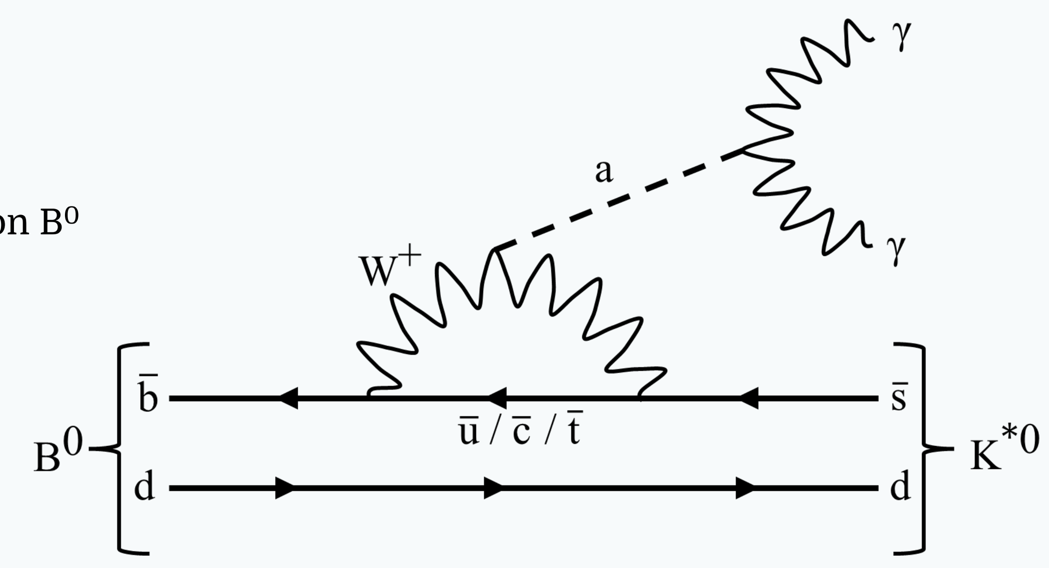

Fig.1 Feynman penguin diagram of the decay channel $B \to K^+\pi^-\gamma\gamma$

This decay involves the conversion of a b-quark to an s-quark via a process known as flavour-changing neutral current [4]. Such processes are highly suppressed in Standard Model decays, which means that the ALP signal, seen as a resonant peak in the diphoton mass spectrum, is more likely to stand out.

Event selection

The project used data from the LHCb, an experiment at the Large Hadron Collider that is dedicated to the study of b-quark physics [5]. Out of all the decay events reconstructed from the detector's outputs, we aimed to select only those corresponding to $B^0 \to K^{*0}\gamma\gamma$. This was achieved in a selection procedure involving cuts and multivariate analysis, that aimed to improve the signal-to-background ratio of the data sample.

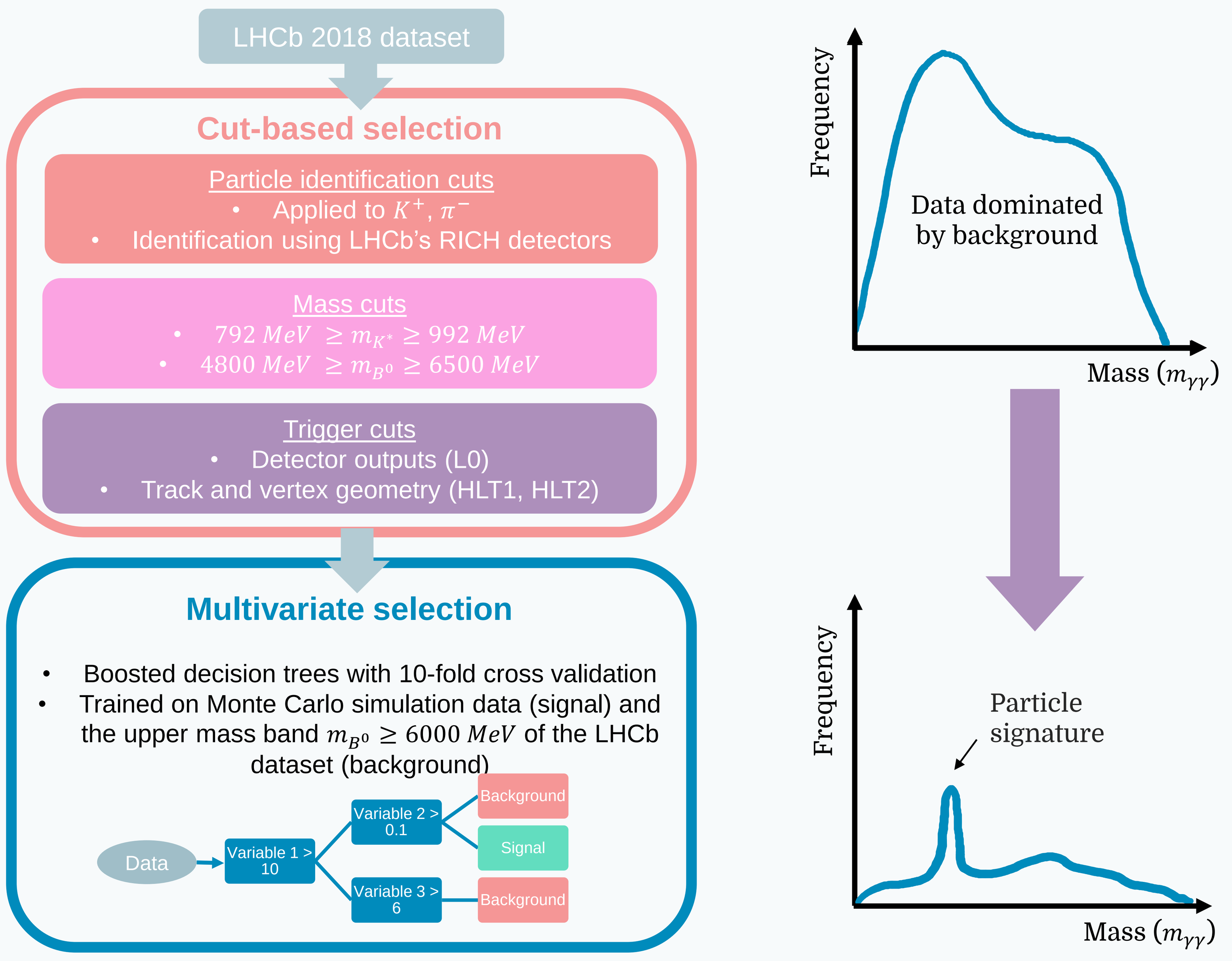

Fig.2 Visualisation of the selection produce for decay $B^0 \to K^{*0}\gamma\gamma$ (left) and the impact of the selection procedure on the diphoton mass spectrum (right) .

Fitting

The background entries that remained in the data after selection had to be accounted for by fitting. Two main sources of background were considered:

- Combinatorial – A combination of particles from different decays mimicking a signal.
- Partially reconstructed – particles from an unwanted decay channel mimic a signal when one of its products is missed ($B \to \pi^0\ K^+\pi^-\ \gamma\gamma$).

The mass spectrum of the B-meson in the selected data was fitted with a function consisting of components for signal, combinatorial background, and partially reconstructed decays. The shapes of the signal and partially reconstructed components were fixed based on simulation data analysis.

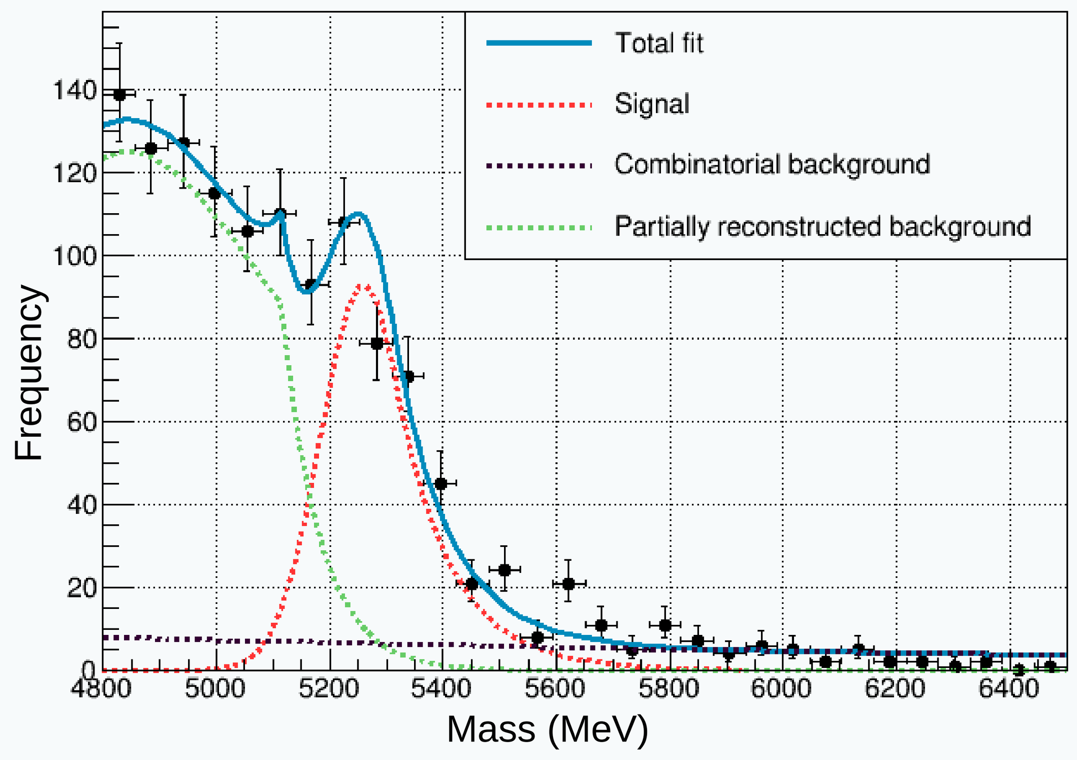

Fig.3 Fit of the selected data used to measure the yields of the signal and the sources of background.

Preliminary Results

Validation with the $B^0 \to K^*\eta$ channel

- Expected yield calculated based on simulation signal efficiency after selection: 103 ± 18
- Measured yield: 70 ± 9
- Discrepancy possibly due to systematic uncertainties in the modelling of the signal in the Monte Carlo simulations

ALP to W coupling

Once the number of η mesons in the data (N_η) and their selection efficiencies (ε_η) were measured, they could be used to derive the branching ratio of $B^0 \to K^{*0}\gamma\gamma$ using

$$\left(BR(B \to K^*\gamma\gamma)\right)_i = \frac{(N_{\gamma\gamma})_i}{N_\eta}\frac{\varepsilon_\eta}{(\varepsilon_{\gamma\gamma})_i} BR(B \to K^*\eta)$$

where i labels a bin in the diphoton mass spectrum. By assuming an approximately constant efficiency $\varepsilon_{\gamma\gamma}$ across the mass range, we calculated the branching fraction as a function of mass.

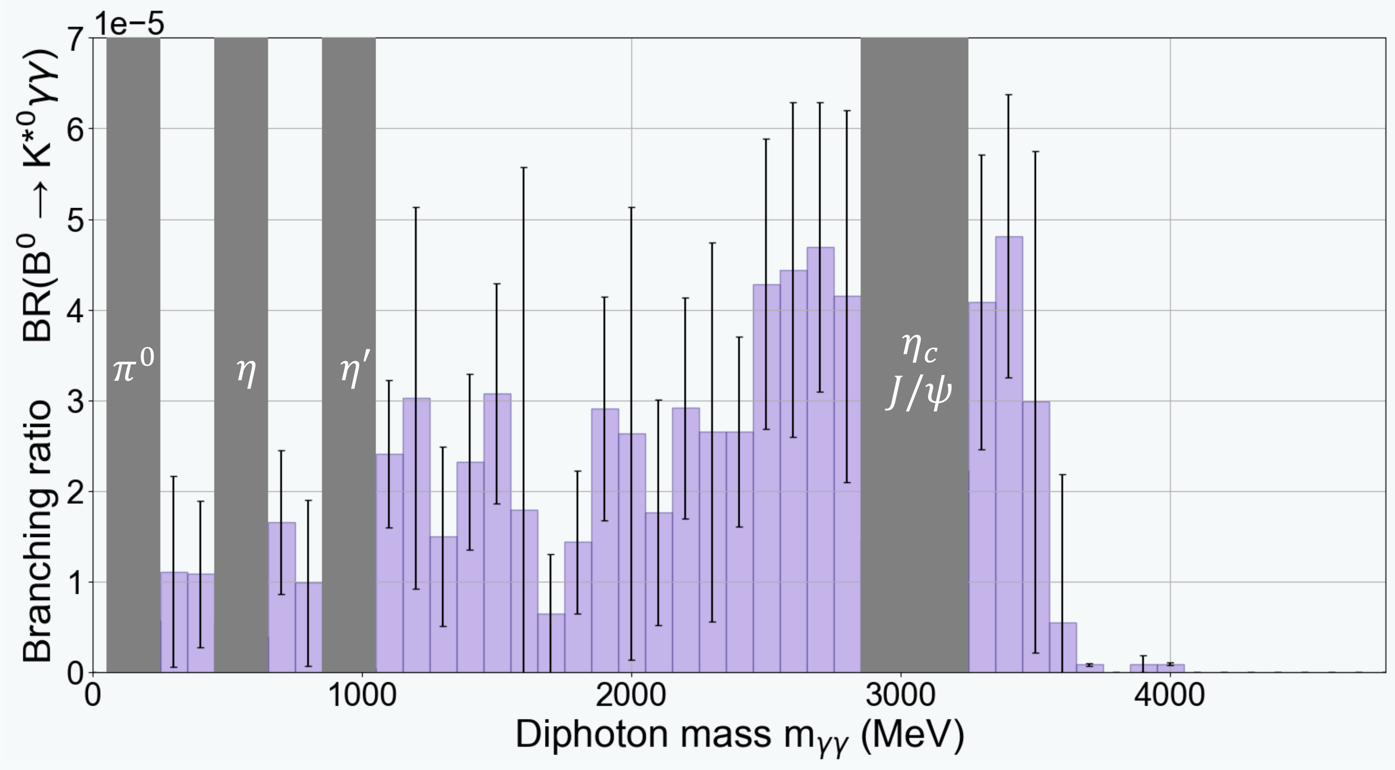

Fig.4 Branching fraction for decay $B^0 \to K^{*0}\gamma\gamma$ as a function of diphoton mass, with the mass regions occupied by known particles ($\pi^0, \eta, \eta', \eta_c, J/\psi$) shaded in grey to avoid misidentification.

Once the branching fraction was calculated, it could then be translated into the ALP to W coupling parameter [3].

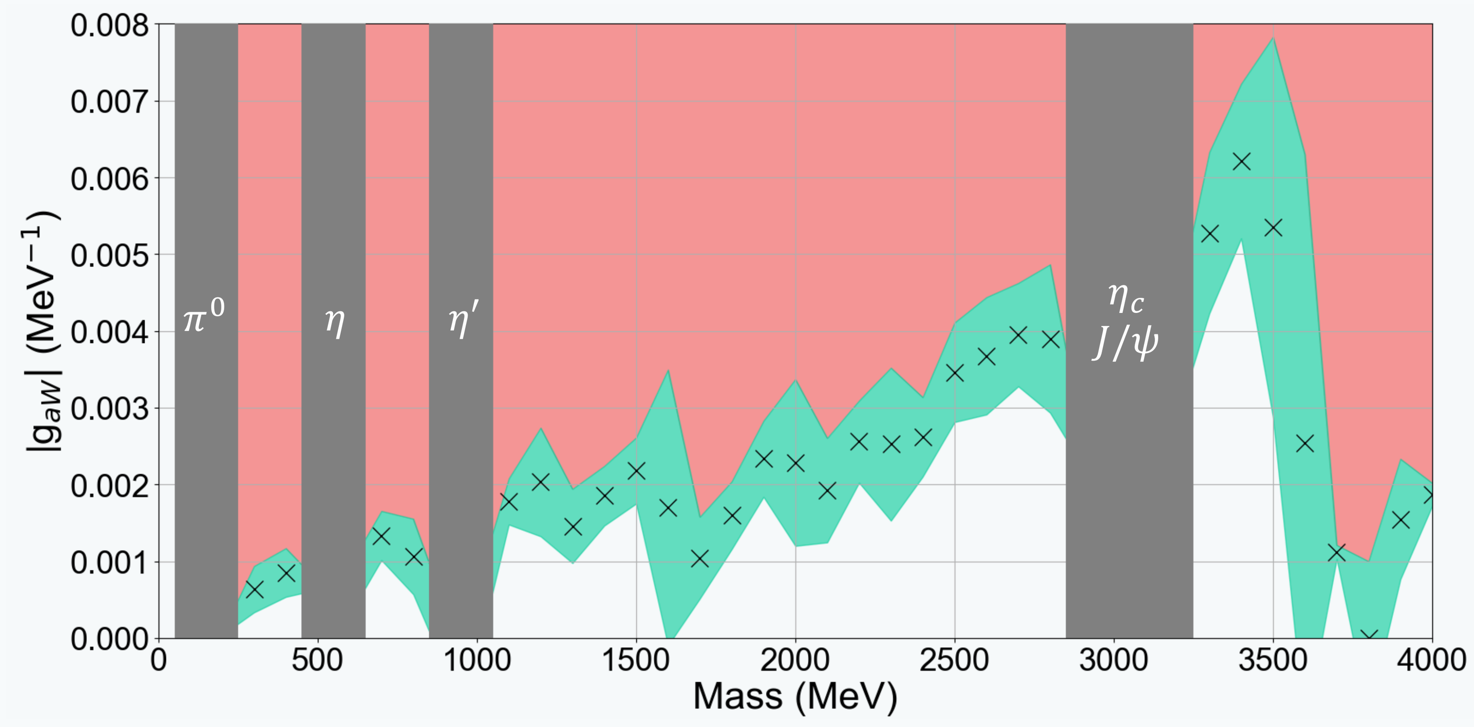

Fig.5 . ALP to W boson coupling constant g_{aW} as a function of diphoton mass, with the uncertainties (green) and exclusion region (red) set by the measurements of the branching ratio $B^0 \to K^{*0}\gamma\gamma$

Conclusion & Further work

- Preliminary results on the branching fraction $B^0 \to K^{*0}\gamma\gamma$ restrict the ALP coupling to W bosons to g_{aW} < 1x10^{-4} MeV^{-1} for ALP masses between (0,4000) MeV.
- The uncertainties are currently highly dominated by statistical errors. To improve our measurement precision, we aim to perform the same analysis on a larger dataset.
- For improved accuracy in our branching fraction, we can find a more accurate value of $\varepsilon_{\gamma\gamma i}$ by calculating it as a function of the diphoton mass.
- Future work will include a resonance search across the whole diphoton mass spectrum. This will involve scanning across the diphoton spectrum with appropriate binning and comparing the likelihoods of the best-fit background-only and signal hypotheses at each step.
- The diphoton resonance search, together with the improved measurement of g_{aW}, will provide some of the first-ever limits on GeV-range ALPs from $B^0 \to K^{*0}a$ decays.

References

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