EPJ Web of Conferences **245**, 06030 (2020) https://doi.org/10.1051/epjconf/202024506030
CHEP 2019

Monte Carlo event generator with model-independent new physics effects for $B \to K^{(*)}\ell\ell$ decays

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Abstract. At high luminosity flavor factory experiments such as Belle II, global analyses with many observables are important to find new physics. Because the observables obtained by assuming the Standard Model could be changed by new physics effects in the kinematic distribution, such effects must be estimated with the detector simulation. We develop the event generator of $B \to K^*\ell\ell$ decays including new physics effects in the model-independent way by parametrizing with the Wilson coefficients based on the EvtGen and EOS. An example of the kinematic distribution is shown, including possible new physics effects in Wilson coefficients.

1 Introduction

The B factory experiments have been playing an important role in the verification of the Standard Model (SM). Especially B decay measurements in the B factory experiments, Belle and BaBar, provide various constraints in the global analysis of the Cabibbo-Kobayashi-Maskawa (CKM) matrix parameters [1–4]. The latest results are consistent with the SM expectation [2–4]. However, statistical uncertainties still dominate the measurement errors and there is still a room for new physics beyond the SM. Therefore, at the high luminosity flavor factory experiments such as the Belle II experiment, there is a possibility to find new physics effects and constrain new physics models with various high statistics observables [5]. In such new physics studies, global analyses of many observables with a model-independent approach is important. One difficulty in such global analyses is that new physics could affect the numerical results obtained by experiments assuming the SM, because of possible changes of the kinematic distributions used in the event selection and in the fitting to obtain the number of signal and background events. Therefore, it is also important to have the event generator including new physics effects for the Monte Carlo simulation of the detector response to estimate and consider the effects properly in the global analyses.

In this proceedings, we present development of the event generator of $\bar{B} \to \bar{K}^*\ell\ell$ ($\ell = e$ or μ) decays including new physics effects in the model-independent way by parametrizing with Wilson coefficients. The $\bar{B} \to \bar{K}^*\ell\ell$ decays are one of the most sensitive B decays to search for new physics beyond the SM. Actually indication of deviation from the SM expectation is reported in several observables [6, 7]. Improved measurements in future will be one of the most important ingredients in the global analyses to search for new physics.

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2 Event Generator Implementation

We implement the decay model using the EvtGen [8] framework so that it can be applicable in analysis software frameworks of experiments at particle colliders. The EvtGen is written in C++ and can be extended by adding decay model classes inheriting the EvtDecay class. There are two main decay model classes to extend decay models, EvtDecayAmp and EvtDecayProb. The EvtDecayAmp is used to calculate complex spin-dependent decay amplitudes. It can be connected to the mother and daughter decays described by the EvtDecayAmp and provide the full spin correlations in the decay tree. The EvtDecayProb is used to provide a probability for given kinematic variables of daughter particles. It is a simpler and more traditional way and applicable to decays to final state particles in the detector simulation. The EvtDecayAmp type model is useful in the decays such as $\bar{B} \to D^*\tau\bar{\nu}$[1] in which spin correlations of decays of daughter particles, D^* and τ, are important. For $\bar{B} \to \bar{K}^*\ell\ell$ decays, we apply EvtDecayProb class, taking into account $\bar{K}^* \to K\pi$ decay and considering the K, π, and two leptons to be the final state particles.

The decay kinematics of the $\bar{B} \to \bar{K}^*\ell\ell$, $\bar{K}^* \to K\pi$ decays is described by four variables, q^2 which is the invariant mass of the two lepton system and three angle parameters, $\cos\theta_l$, $\cos\theta_K$ and ϕ. For the three angles there are several definitions used in theory and experiment papers. We use the definition of the LHCb experiment [9], which is also used in other experiments. For the decay $\bar{B}^0 \to \bar{K}^{*0}\ell^+\ell^-$, $\bar{K}^{*0} \to K^-\pi^+$, the θ_l is defined as the angle between the ℓ^- momentum and the opposite of the $\bar{B}^0$ momentum in the $\ell^+\ell^-$ rest frame, the θ_K is defined as the angle between the K^- momentum and the opposite of the $\bar{B}^0$ momentum in the $\bar{K}^{*0}$ rest frame, and the ϕ is defined as the angle between the two decay planes of $\ell^+\ell^-$ and $K^-\pi^+$.

For the theoretical calculation of the decay probability including new physics effects, we use the EOS library [10]. The EOS is the package to calculate physical observables in various decays including new physics effects and to calculate constraints on new physics effects from the observables. New physics effects are described in the model independent way with Wilson coefficients. It is written in C++ and has functions that give the probability density function (PDF) for given kinematic variables. Therefore, it is an ideal tool to apply to our event generator model.

3 Event Generation Procedure

We have developed two decay models for $\bar{B} \to \bar{K}^*\ell\ell$, $\bar{K}^* \to K\pi$ decays. They correspond to the two EOS calculations for different q^2 regions. In the EvtGen decay.dec, we implement the decay definitions as follows.

```
Decay anti-B0
# Br Daughter particles decay_model parameters
0.5 K- pi+ mu+ mu-  EvtEOSLargeRecoil 1 6 bsll.yaml;
0.5 K- pi+ mu+ mu-  EvtEOSLowRecoil 14 19 bsll.yaml;
Enddecay
```

"EvtEOSLargeRecoil" and "EvtEOSLowRecoil" are the model names we developed and corresponds to the EOS signal PDF calculation, `B->K^*ll::d^4Gamma@LargeRecoil` [11] and `B->K^*ll::d^4Gamma@LowRecoil` [12]. The three parameters are q^2 minimum and maximum values and the filename of Wilson coefficient values written in the YAML format.

In the EvtGen, the EvtEOSLargeRecoil and EvtEOSLowRecoil models generate decay events with the following procedure:

[1] we are also working on the development of the EvtGen decay model for $\bar{B} \to D^*\tau\bar{\nu}$ with new physics effects.

1. generate mass of $\bar{K}^*$ randomly in Breit-Wigner distribution,
2. generate $\bar{K}^*\ell\ell$ momenta randomly and uniformly in the three body phase space,
3. generate $\bar{K}^* \to K\pi$ two body kinematics,
4. calculate four decay kinematic variables q^2, $\cos\theta_l$, $\cos\theta_K$ and ϕ, and
5. decide if this event is kept or not using the probability given by the EOS PDF function. If not taken, return to 1.

Note that because in the procedure above we use the phase space distribution in the generation already, we remove the phase space term from the PDF value given by EOS in 4.

To validate the developed model, we compare generated events with our decay models with the PDF values directly obtained from EOS as the reference. We generate 100 thousands events of $\bar{B}^0 \to \bar{K}^{*0}\mu^+\mu^-$, $\bar{K}^{*0} \to K^-\pi^+$ decay for each of "EvtEOSLargeRecoil" and "EvtEOSLowRecoil" for the SM assumption. We confirm the generated distributions are consistent with the EOS PDF values and conclude the developed model works properly.

4 Event Generation with New Physics Effect

To test the possible new physics effects in the generated distributions and momenta of daughter particles which is important for the actual detector response, we generate 100 thousands events including new physics effects by modifying Wilson coefficients. Figure 1 shows the forward-backward asymmetry, q^2, $\cos\theta_l$, $\cos\theta_K$ and ϕ distributions for the "EvtEOSLargeRecoil" model for two cases: SM (red points) and a possible new physics case (blue points). For the possible new physics case, we modify Wilson Coefficients $C9$ and $C10$ by -0.73 and $+0.40$, which are the best fit values in [13]. We see there are visible differences between two cases. The distributions of momenta of daughter particles are shown in Figure 2. We see the distributions are changed. Though the differences are not so large in this case, such differences can affect the detector response and will be important in precise measurements in the high statistics flavor factory experiments.

5 Summary

At the high luminosity flavor factory experiments such as Belle II, the global analyses of various measurements will be a strong tool to search for new physics. In such analyses, it is also important to take into account the changes of the kinematic distributions due to new physics effects that can affect the reconstruction efficiencies and fits to obtain the signal yields. Based on the EvtGen and EOS libraries, we have developed the event generator for $\bar{B} \to \bar{K}^*\ell\ell$ decays, which are one of the most sensitive decay modes to new physics, with new physics effects included in the model independent way with Wilson coefficients. We confirm our developed model generate the event kinematics including new physics effects properly. We will extend our work to other decay modes such as $\bar{B} \to K\ell\ell$ and $\bar{B} \to D^{(*)}\tau\bar{\nu}$ and study the global analysis including them in future.

Acknowledgement

We thank Danny van Dyk and Christoph Bobeth for their kind help and many fruitful discussions on implementing EOS in our event generator model. This work is supported by JSPS KAKENHI Grant Number JP16H03993.

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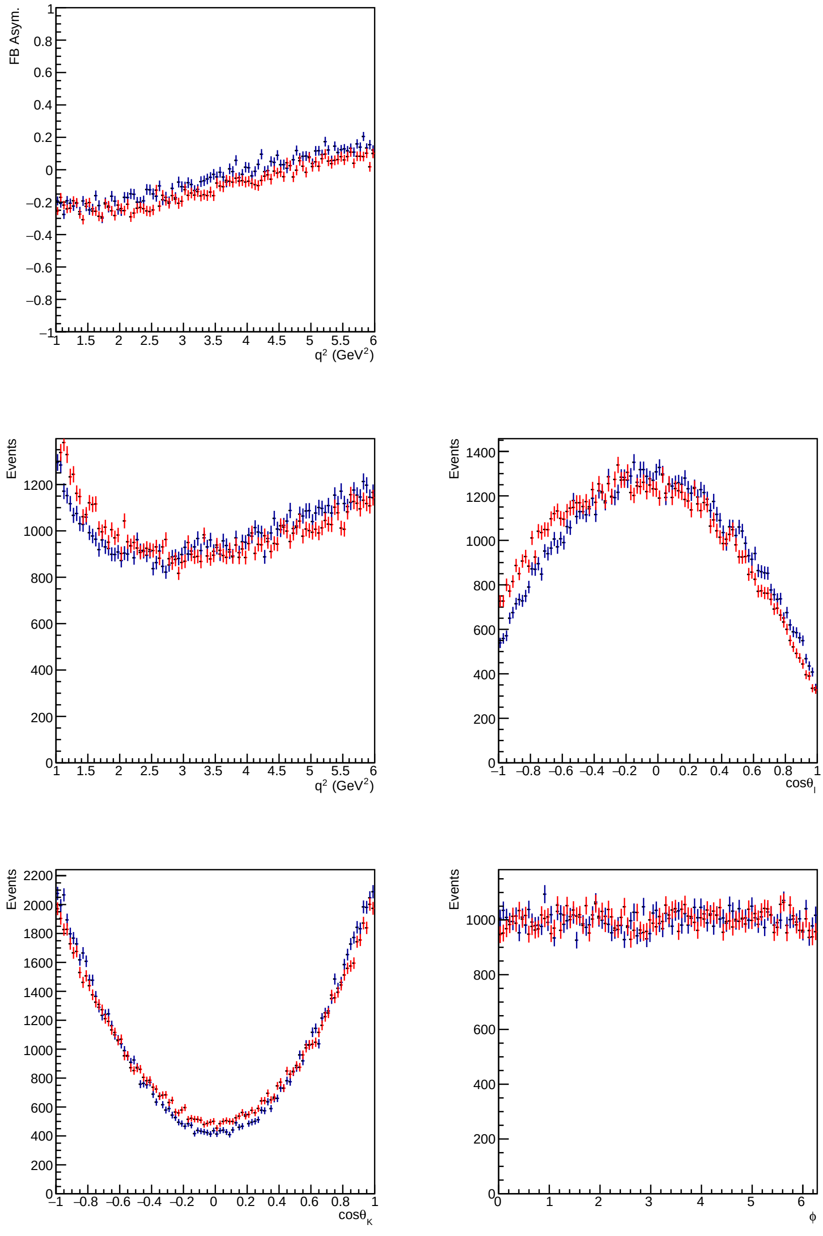

Figure 1. The forward-backward asymmetry, q^2, $\cos\theta_l$, $\cos\theta_K$ and ϕ distributions for $\bar{B}^0 \to \bar{K}^{*0}\ell^+\ell^-$, $\bar{K}^{*0} \to K^-\pi^+$ decays generated with the "EvtEOSLargeRecoil" model. The SM expectation is shown as red points and a possible new physics case in which $C9$ and $C10$ are modified by -0.73 and $+0.40$ is shown as blue points.

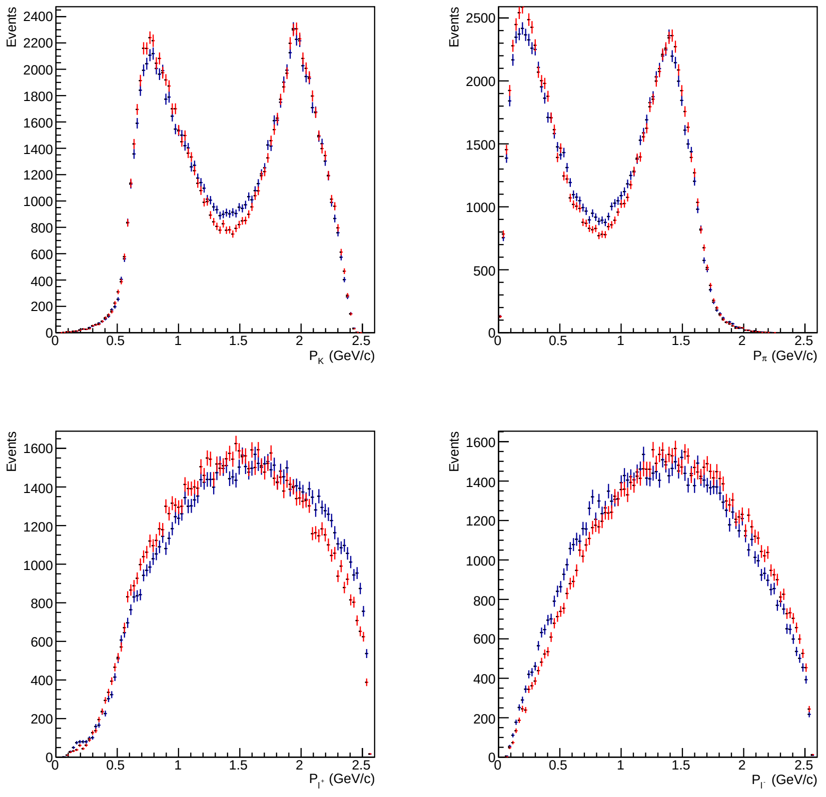

Figure 2. The distributions of momenta of daughter particles for $\bar{B}^0 \to \bar{K}^{*0}\ell^+\ell^-$, $\bar{K}^{*0} \to K^-\pi^+$ decays generated with the "EvtEOSLargeRecoil" model. The SM expectation is shown as red points and a possible new physics case in which $C9$ and $C10$ are modified by -0.73 and $+0.40$ is shown as blue points.