Monte Carlo event generator with model-independent new physics effect for $B \to K(\ast)\ell\ell$ decays

Koji Hara, Ryosuke Itoh, Satoshi Mishima, Hideki Miyake

High Energy Accelerator Research Organization (KEK)
Physics of $B \rightarrow K^{*} \nu \bar{\nu}$ Decay

- $b \rightarrow s$ penguin decay, sensitive to new physics beyond the Standard Model
- $>\sim 2\sigma$ deviation from SM in several measurements such as decay angle distribution and $R_{K^{*}}(\mu\mu/ee)$
- Promising decay mode in the new physics analysis

Deviations in LHCb

$B^{0} \rightarrow K^{+}\nu \bar{\nu}$

Deviation in $P'_{L}$ of muon mode with 2.6$\sigma$
Global Analysis of New Physics in High Statistics Experiment

Previous generation of B factory experiment: global analysis of CKM within SM
→ In high statistics experiment such as BelleII: NP analysis with deviation from SM
→ Global analysis including new physics in model-independent way is necessary

\[ H_{\text{eff}} = H_{\text{eff}}^{\text{SM}} - \frac{4G_F}{\sqrt{2}} V_{tq}^* V_{tb} \sum_i C_i^{\text{NP}} O_i \quad \text{for } b \rightarrow sll \]

\( C_i^{\text{NP}} \): Wilson Coefficients characterizing NP models
Need for MC Event Generator including New Physics

• Measurements by Experiments
  : Need fitting to data, correction of reconstruction efficiencies
• Distribution and efficiencies obtained with MC usually assuming SM
  o New Physics can affect the shape used in the fit, kinematic
distribution and efficiencies
→ Develop MC event generator including NP
• As EvtGen decay model class
• Model-independent method by parametrizing with Wilson Coefficients

\[ H_{\text{eff}} = H_{\text{eff}}^{\text{SM}} - \frac{4G_F}{\sqrt{2}} V_{tq}^* V_{tb} \sum_i C_i^{\text{NP}} O_i \]

We are working on $B \rightarrow K^{*}ll$, and also $Kll$, $D(*)\tau\nu$
Adding Decay model to EvtGen

EvtGen:

- MC event generator for B decays commonly used in B physics experiments
  - Developed by Anders Ryd, David Lange. Maintained by Univ. of Warwick group now.
  - Includes decays of B daughters such as D, K*, τ etc.
  - Written in C++

- New decay models can be added by creating C++ class inheriting EvtDecay
  - Several variant types: EvtDecayAmp, EvtDecayProb etc.

EvtDecayAmp: **Give complex decay amplitude** with spin dependence

- Connectable to arbitrary daughter particle decays using EvtDecayAmp with proper spin correlation
- Main decay models in EvtGen
  - Example: B→D*ν : ISGW2 model
  - D* → Dπ : VSS model
  - D → Kπ : PHSP model
  - Need to be written with EvtGen’s classes of spinor, current etc.
  - B→D*τν decay needs this approach

EvtDecayProb: **Give decay probability**

- Not usable for daughter particles that still decays with EvtDecayAmp
- Acceptable if it decays to long lived particles (K, π, μ, e etc.)

Used for this work of B→K* ll
By treating as B → K π l+ l- decay

CHEP2019
B\rightarrow K^{*}\pi\ell\ell Decay Probability

- Implement with EvtDecayProb
- 4 final state particles: B\rightarrow K^{*}(\rightarrow K\pi) \pi^{+}\pi^{-}

- This time we utilized the EOS library for the decay probability calculation

EOS — A HEP program for Flavor Observables [https://eos.github.io]
  - Developed by van Dyk, Danny and others
  - **C++ code package** → Provide functionality as C++ library
  - Framework to perform theoretical calculation of various flavor physics observables
  - Including B\rightarrow K(*)\ell\ell decay probability
Kinematic Parameters of $B \to K^*\ell\ell, K^* \to K\pi$

- $B \to K^*\ell\ell, K^* \to K\pi$ decay is described by 4 kinematic parameters
  (In case of $\bar{B}$ decay)
  - $q^2$ : (invariant mass of $\ell\ell$ system)$^2$
  - $\cos \theta_{\ell}$: cos of helicity angle of $\ell$
  - $\cos \theta_K$: cos of helicity angle of $K$
  - $\phi$: angle between decay planes of $K\pi$ and $\ell\ell$ ($0-2\pi$)

**NOTE:** Definitions used in experiment and theory are different

In case of $\bar{B}$ decay

- Experiment $\to$ EOS
  - $\cos \theta_{\ell} \to -\cos \theta_{\ell}$
  - $\cos \theta_K \to -\cos \theta_K$
  - $\phi \to \phi$

(Other definitions are also used in theory papers)
Event Generation in EvtGen

1. Produce $K^*$ mass randomly

2. Produce $B \rightarrow K^*\pi$ kinematics uniformly in the three-body phase-space

3. Produce $K^* \rightarrow K\pi$ two body kinematics

4. Get $B \rightarrow K^*\pi, K^* \rightarrow K\pi$ decay probability calculated by EOS library
   - Correct the phase-space term

5. EvtGen make decision by acceptance-rejection method → take the event or return to 1
Developed EvtGen Decay Model

- Prepared two decay models for different q² regions
  - EvtEOSLargeRecoil: small q² range, ~1<q²<~6 GeV²
    Using EOS signal PDF of “B->K^(*)l:ll:d^4Gamma@LargeRecoil” (arXiv:0805.2525)
  - EvtEOSLowRecoil: large q² range, ~14<q²<~19 GeV²
    Using EOS signal PDF of “B->K^(*)l:ll:d^4Gamma@LowRecoil” (arXiv:1006.5013)

- User decay.dec
  Decay MyB0B
  
  # Br daughter particles decay model name parameters
  1.0 K- pi+ mu+ mu- EOSLargeRecoil 1 6 bsll.yaml;

  Enddecay
  
  # parameters: q² min, max and Wilson Coefficient parameter file

- Wilson Coefficients given by yaml format file
  Example
  "b->s::c1":
    central: -0.29063621
    min:   -0.29063621
    max:   -0.29063621
Test of Event Generation with
Developed $B \rightarrow K^* \mu \mu$ Decay Model

- Compare SM and SM + NP case for Large Recoil ($1 < q^2 < 6$ GeV$^2$)
  - Generated $10^5$ events of $B^0 \rightarrow K^{*0} \mu^+ \mu^-$, $K^{*0} \rightarrow K^\pm \pi^\mp$
  - No detector simulation
  - Evaluate distributions of
    - Basic kinematic parameters $q^2$, $\cos \theta_l$, $\cos \theta_K$, $\phi$
    - Forward-Backward asymmetry
    - Momenta of $K, \pi, l^+, l^-$ in $B$ rest frame

1) Compare SM and modified C9, C10

2) Change C7

J. Aebischer et al. [arXiv:1903.10434]

Red: SM
Blue: (C9,C10)=(-0.73,+0.40)

Large Recoil $q^2$ 1-6 GeV$^2$

Events

$cos \theta_l$

$cos \theta_K$

$\phi$

$P_{K}$ (GeV/c)

$P_{\pi}$ (GeV/c)

$P_{l^+}$ (GeV/c)

$P_{l^-}$ (GeV/c)

Events

Events

Events

Events

Events

Events

Events

Events

Events
Large Recoil $q^2 1-6 \text{ GeV}^2$

Blue: C7 +0.027
Red: C7 -0.032

CLEO-C "2019"
Summary

• In high statistics flavor experiment, global analysis including new physics will be performed
  → Model-independent approach using Wilson Coefficients will be effective
• The new physics effect should be included in the experimental analysis in the same way
  → Need MC event generator including new physics
• We develop MC event generator for $B \to K^{*}\ell\ell$ decays
  o Implemented as a decay model of EvtGen
  o Utilize EOS library for theoretical calculation Wilson Coefficients
  o Verify the distribution for some NP cases
• We will also develop generators for other decays, $B \to K\ell\ell$ and semi-tauonic decays, and prepare the global analysis for the high statistics flavor data of Bellell and other experiments

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CHEP2019
Low Recoil $q^2$ 14-19 GeV$^2$

Red: SM
Blue: $(C9, C10) = (-0.73, +0.40)$

Large Recoil $q^2$ 1-6 GeV$^2$

Red: SM
Blue: $(C9, C10) = (-0.73, +0.40)$
Red: SM
Blue: (C9,C10)=(-0.73,+0.40)

Large Recoil $q^2$ 1-6 GeV$^2$

Low Recoil $q^2$ 14-19 GeV$^2$
Difference is small in Low Recoil $q^2$.
Large Recoil $q^2$ 1-6 GeV$^2$

Blue: C7 +0.027  
Red: C7 -0.032

Low Recoil $q^2$ 14-19 GeV$^2$

Blue: C7 +0.027  
Red: C7 -0.032
Wilson Coefficient for $B \rightarrow K^{*}\pi$ Decay in EOS

https://eos.github.io/doc/parameters.html

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$K^{*}_{ee}$

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$K^{*}_{\mu\mu}$

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