Monte Carlo event generator with model-independent new physics effect for B->K(*)ll decays

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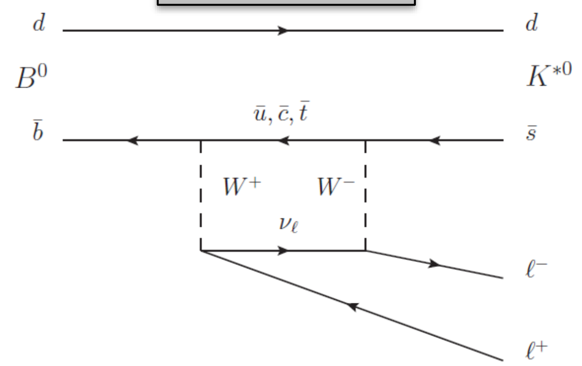
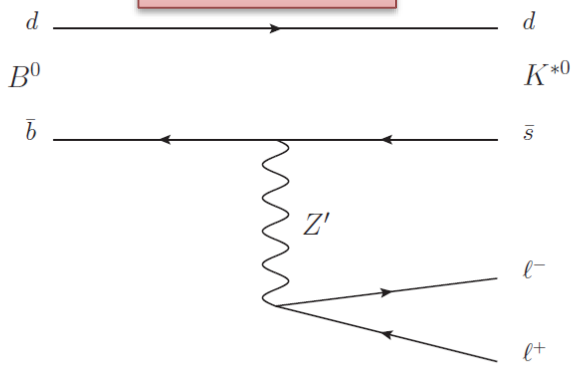
Physics of B→K*ll Decay

SM Example

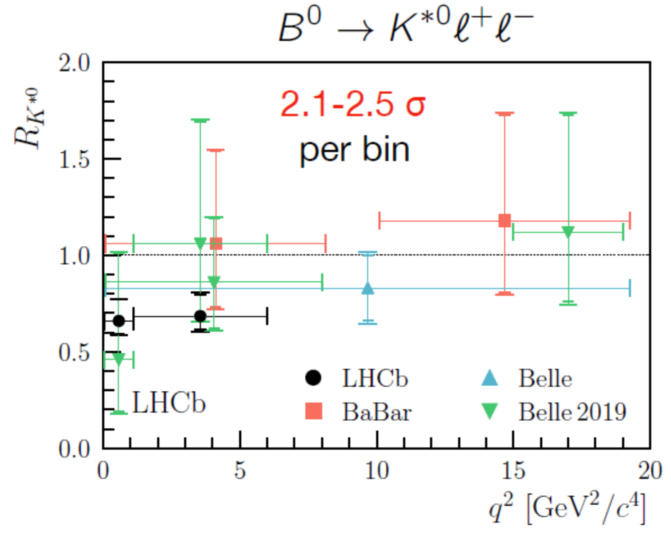


NP Example

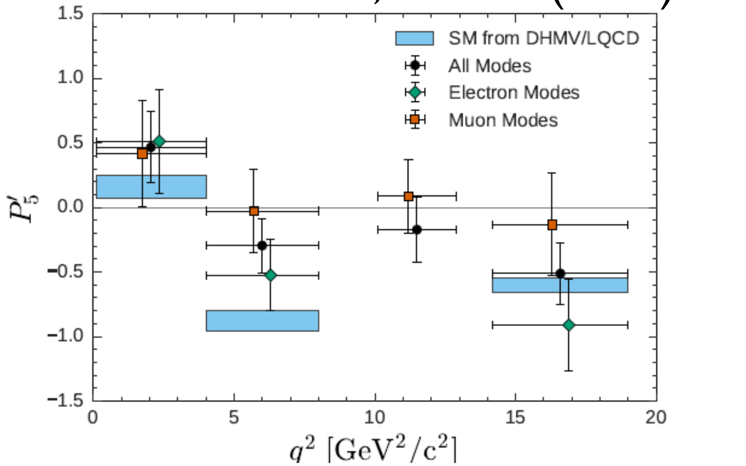


- b→s penguin decay, sensitive to new physics beyond the Standard Model
- >~2σ deviation from SM in several measurements such as decbay angle distribution and R_{K*}(μμ/ee)
- Promising decay mode in the new physics analysis

Deviation in LHCb



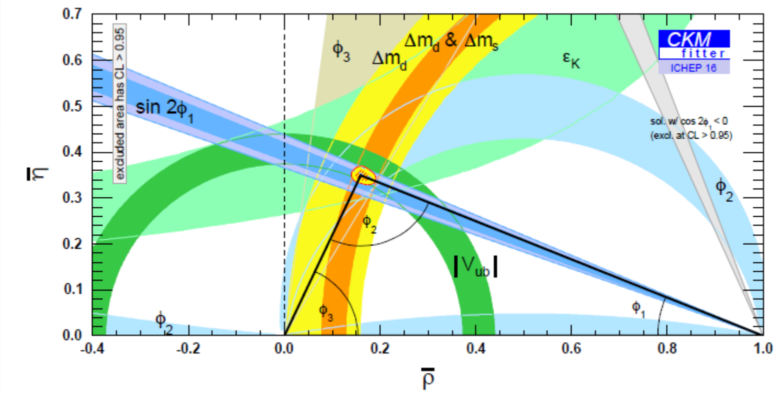
Belle PRL118, 111801 (2017)



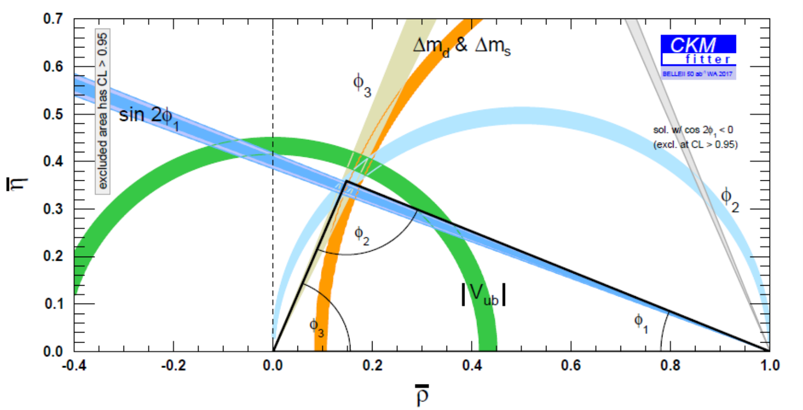
Largest deviation in P'_5 of muon mode with 2.6σ

Global Analysis of New Physics in High Statistics Experiment

CKMfitter (2016)



Current WA with BelleII 50ab[-1] error



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

$$\mathcal{H}_{\rm eff} = \mathcal{H}_{\rm eff}^{\rm SM} - \frac{4G_F}{\sqrt{2}} V_{tq}^* V_{tb} \sum_i C_i^{\rm NP} \mathcal{O}_i$$ for b→sll

C_i^{NP}: Wilson Coefficients characterizing NP models

Need for MC Event Generator including New Phsyics

- Measurements by Experiments

  : Need fitting to data, correction of reconstruction efficiencies

- Distribution and efficiencies obtained with MC usually assuming SM
  - 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

$$\mathcal{H}_{\text{eff}} = \mathcal{H}_{\text{eff}}^{\text{SM}} - \frac{4G_F}{\sqrt{2}} V_{tq}^* V_{tb} \sum_i C_i^{\text{NP}} \mathcal{O}_i$$

We are working on B→K*ll, and also Kll, D(*)τν

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*lν : 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

B→K*ll Decay Probability

- Implement with EvtDecayProb
- 4 final state particles : B→ K*(→Kπ) l^+l^-

- 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**
- Frame work to perform theoretical calculation of various flavor physics observables
- Including B→K(*)ll decay probability

Kinematic Parameters of B→K*ll, K*→Kπ

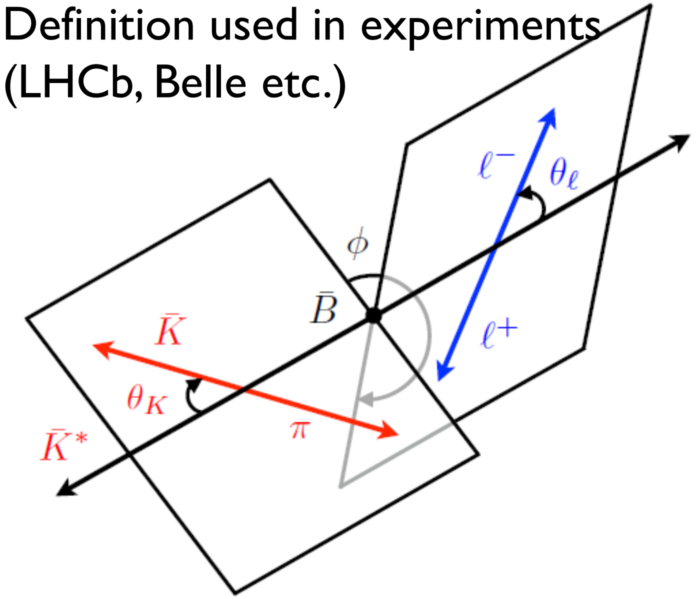
- B→K*ll, K*→Kπ decay is described by 4 kinematic parameters

  (In case of $\bar{B}$ decay)

  - q2 : (invariant mass of ll system)^2
  - $\cos\theta_l$: cos of helicity angle of l^-
  - $\cos\theta_K$: cos of helicity angle of K
  - ϕ : angle between decay planes of Kπ and ll (0-2π)

Give EOS them (and K* mass) and EOS returns decay probability

Definition used in experiments (LHCb, Belle etc.)



<u>NOTE: Definitions used in experiment and theory are different</u>

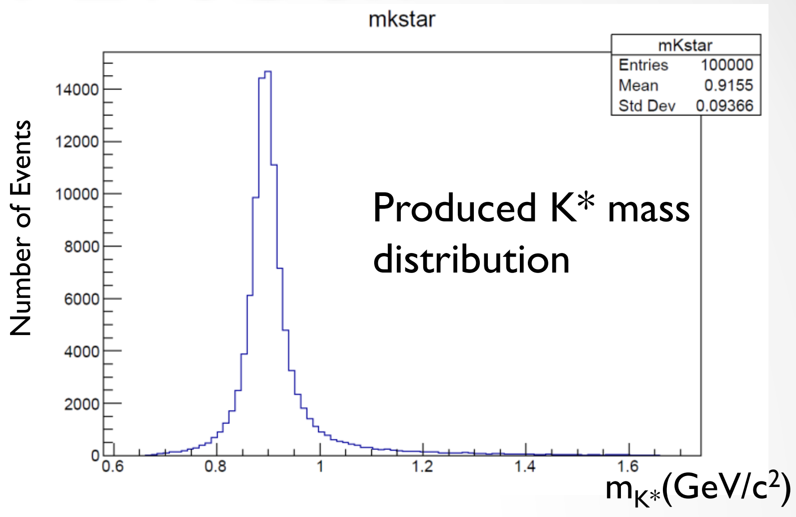
<u>In case of $\bar{B}$ decay</u>

Experiment	→	EOS
$\cos\theta_l$		$-\cos\theta_l$
$\cos\theta_l$		$-\cos\theta_K$
ϕ		ϕ

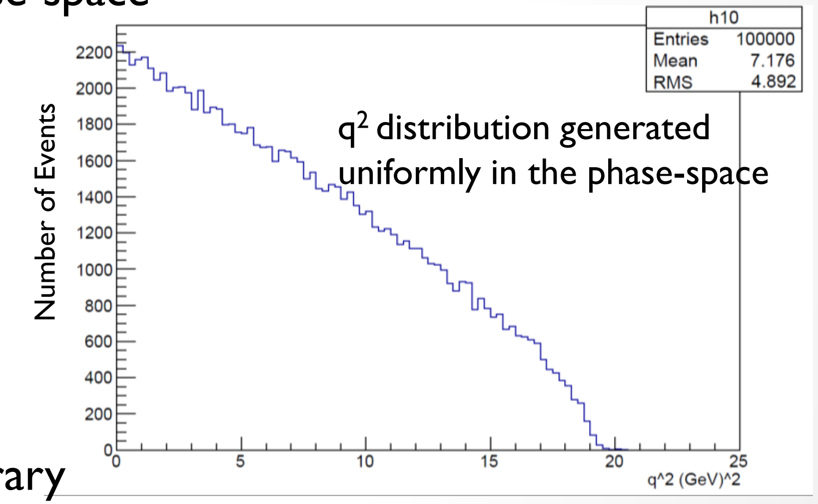
(Other definitions are also used in theory papers)

Event Generation in EvtGen

1. Produce K* mass randomly



2. Produce B→K*ll kinematics uniformly in the three-body phase-space
3. Produce K*→Kπ two body kinematics



4. Get B→K*ll, K*→Kπ 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 q^2 range, $\sim 1 < q2 < \sim 6$ GeV^2
    Using EOS signal PDF of "B->K^*ll::d^4Gamma@LargeRecoil" (arXiv:0805.2525)
  - EvtEOSLowRecoil : large q^2 range, $\sim 14 < q2 < \sim 19$ GeV^2
    Using EOS signal PDF of "B->K^*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
# paramters: q2 min, max and Wilson Coefficient parameter file
```

- Wilson Coefficients given by yaml format file

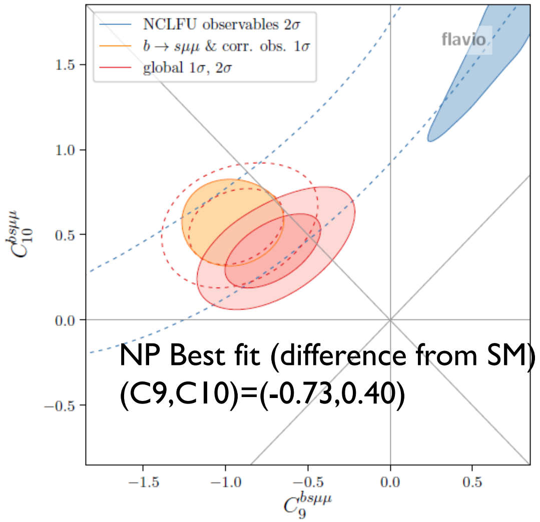
Example)

```
"b->s::c1" :
    central: -0.29063621
    min:     -0.29063621
    max:     -0.29063621
```

Test of Event Generation with Developed B→K*ll Decay Model

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

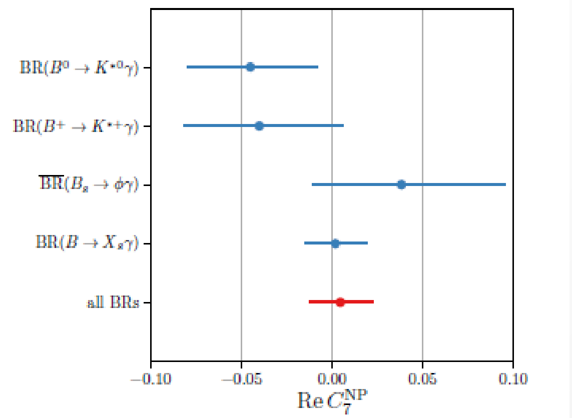
1) Compare SM and modified C9, C10



NP Best fit (difference from SM)
(C9,C10)=(-0.73,0.40)

J.Aebischer et al. [arXiv:1903.10434]

2) Change C7

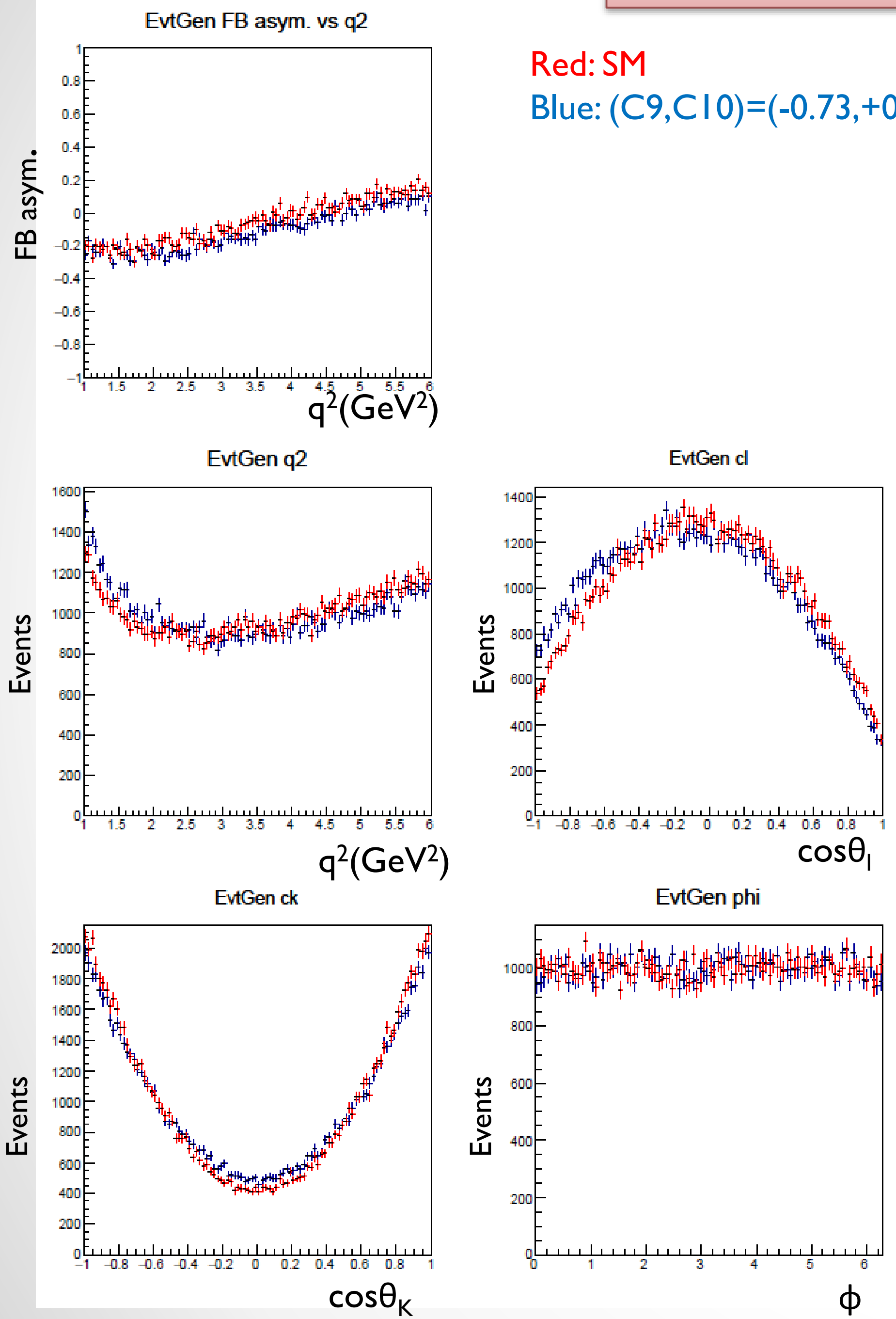


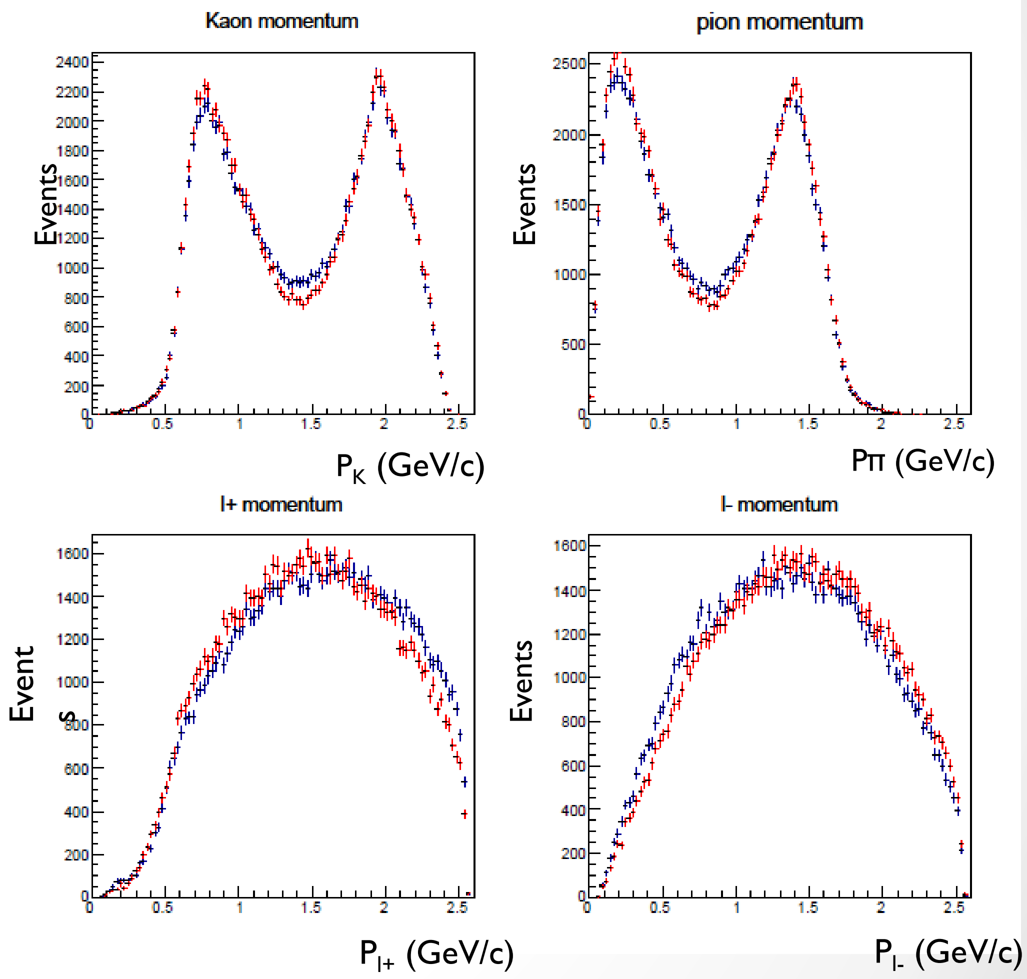
$$\mathrm{Re}\, C_7^{\mathrm{NP}}(\mu_b) \in \begin{cases} [-0.018, 0.012] & @\ 1\sigma, \\ [-0.032, 0.027] & @\ 2\sigma, \end{cases}$$

Ayan Paul, David M. Straub [arXiv1608.02556:]

Large Recoil q2 1-6 GeV²

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

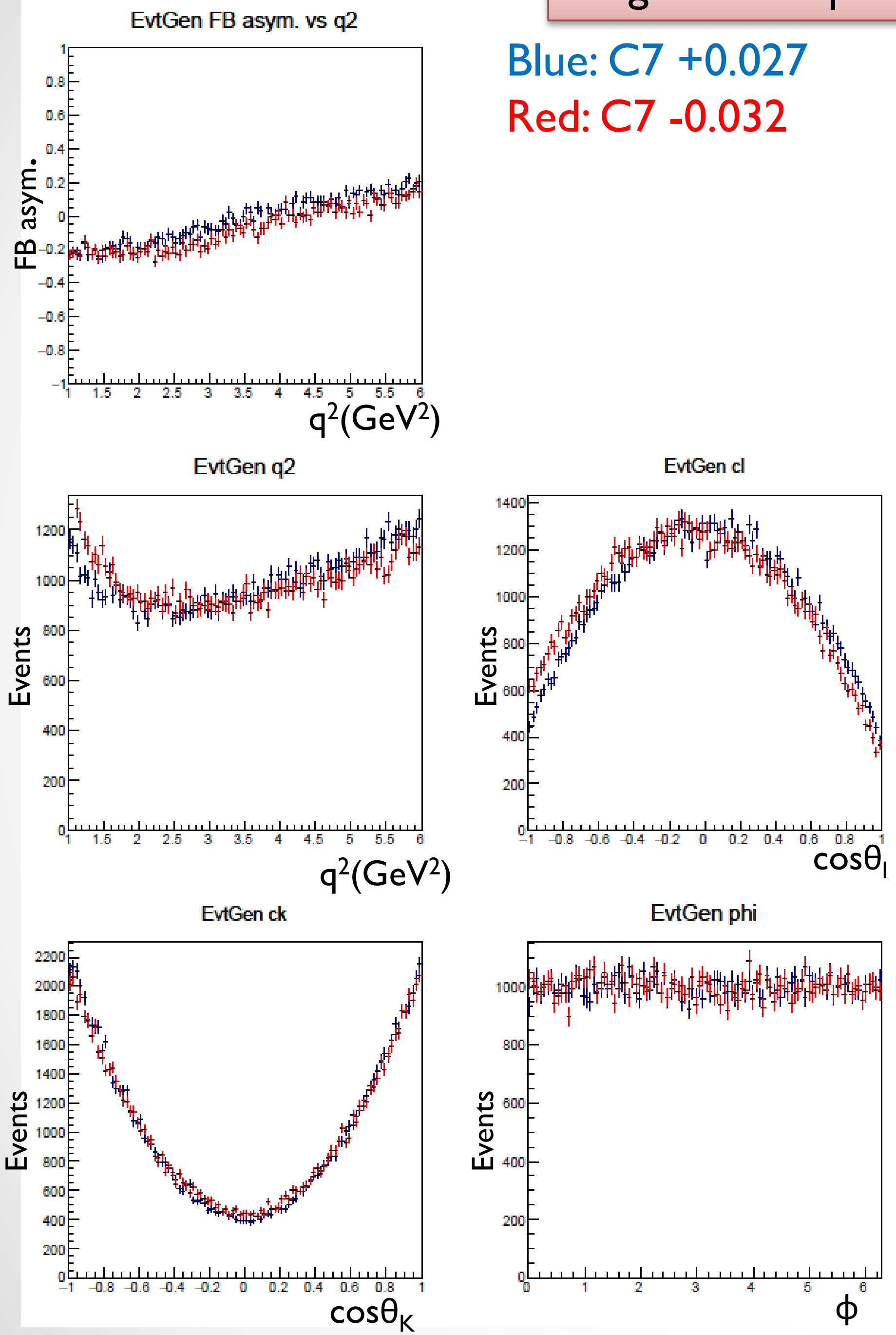


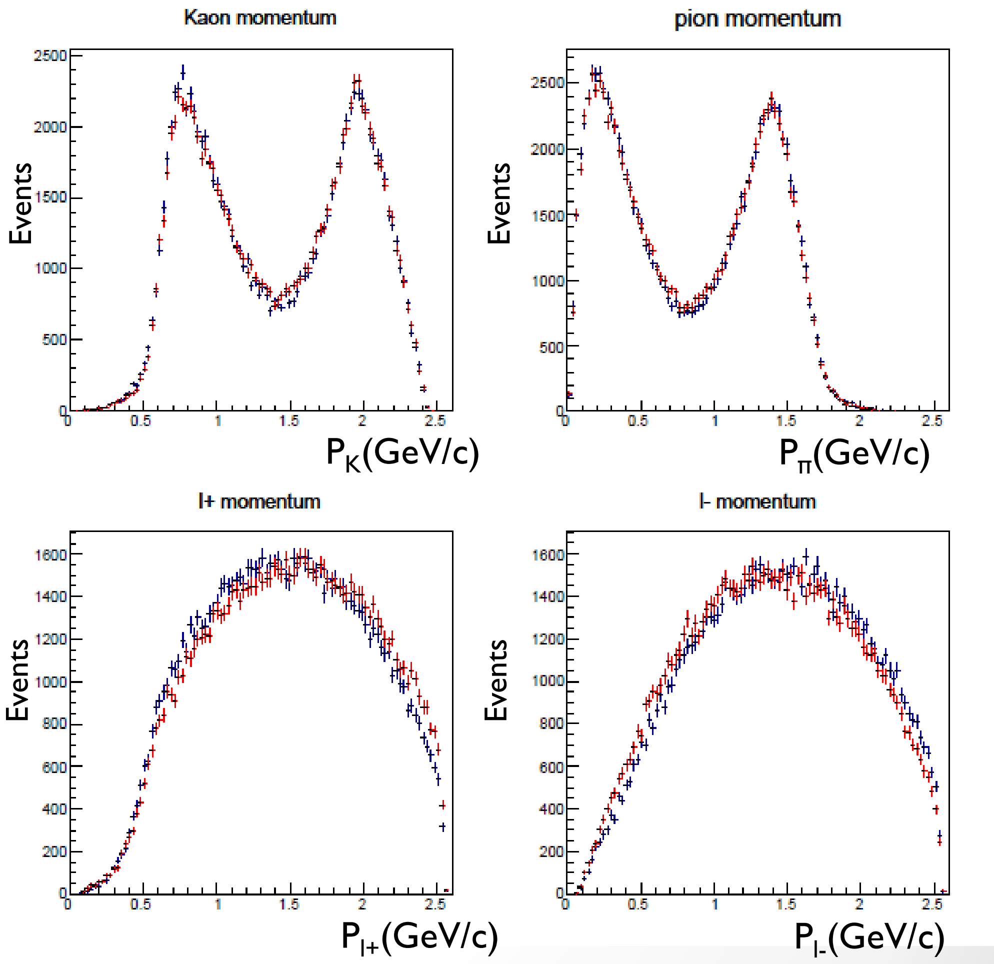


Large Recoil q2 1-6 GeV²

Blue: C7 +0.027

Red: C7 -0.032





Summary

- In high statistics flavor experiment, global analysis including new physics will be performed

→ Model-independent approach using Wilson Coefficients will be effective

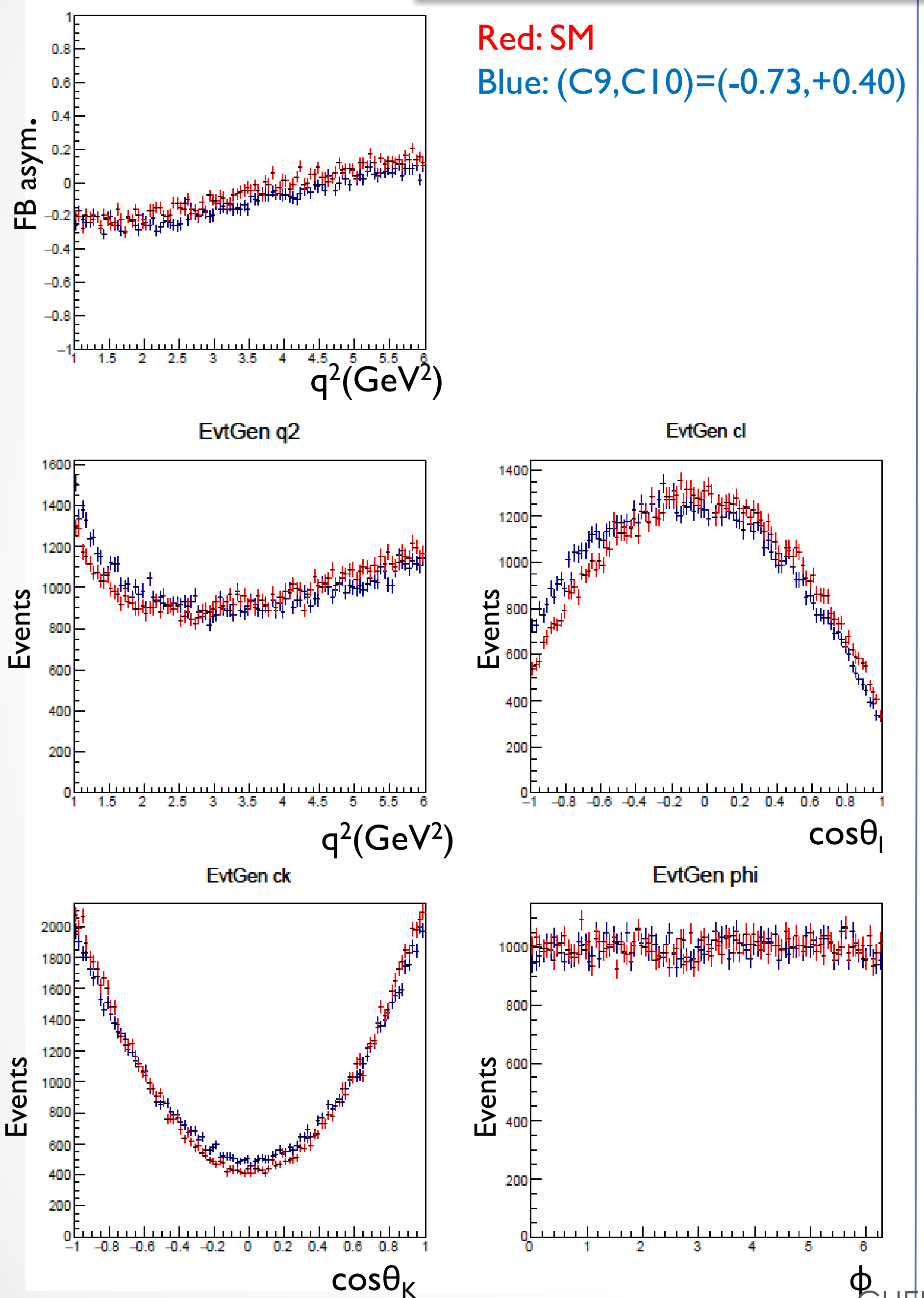
- The new physics effect should be included in the experimental analysis in the same way

→ Need MC event generator including new physics

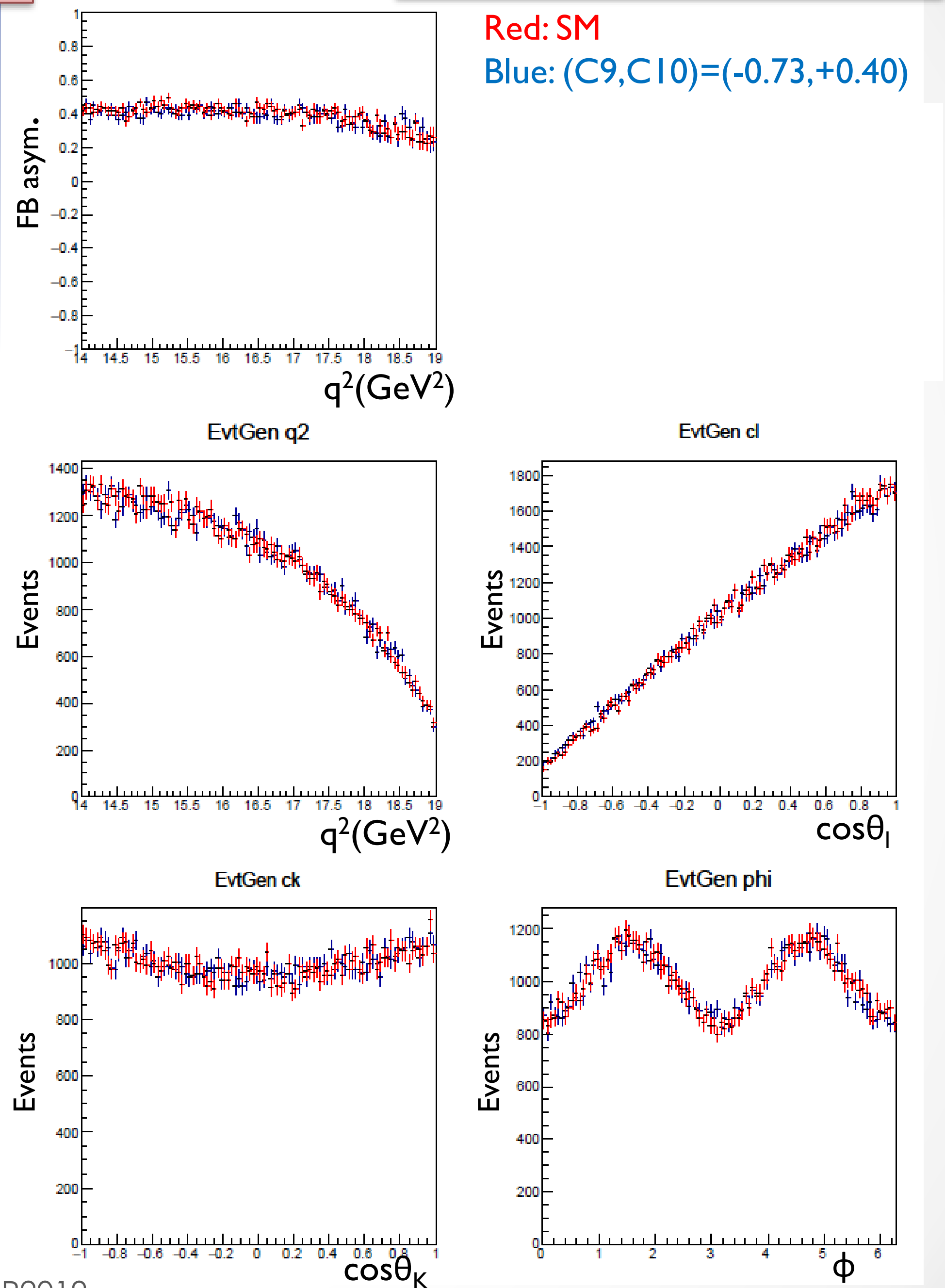
- We develop MC event generator for B→K*ll decays
  - Implemented as a decay model of EvtGen
  - Utilize EOS library for theoretical calculation Wilson Coefficients
  - Verify the distribution for some NP cases
- We will also develop generators for other decays, B→Kll and semi-tauonic decays, and prepare the global analysis for the high statistics flavor data of BelleII and other experiments

This work is supported by JSPS KAKENHI Grant Number JP16H03993

Large Recoil q2 1-6 GeV^2

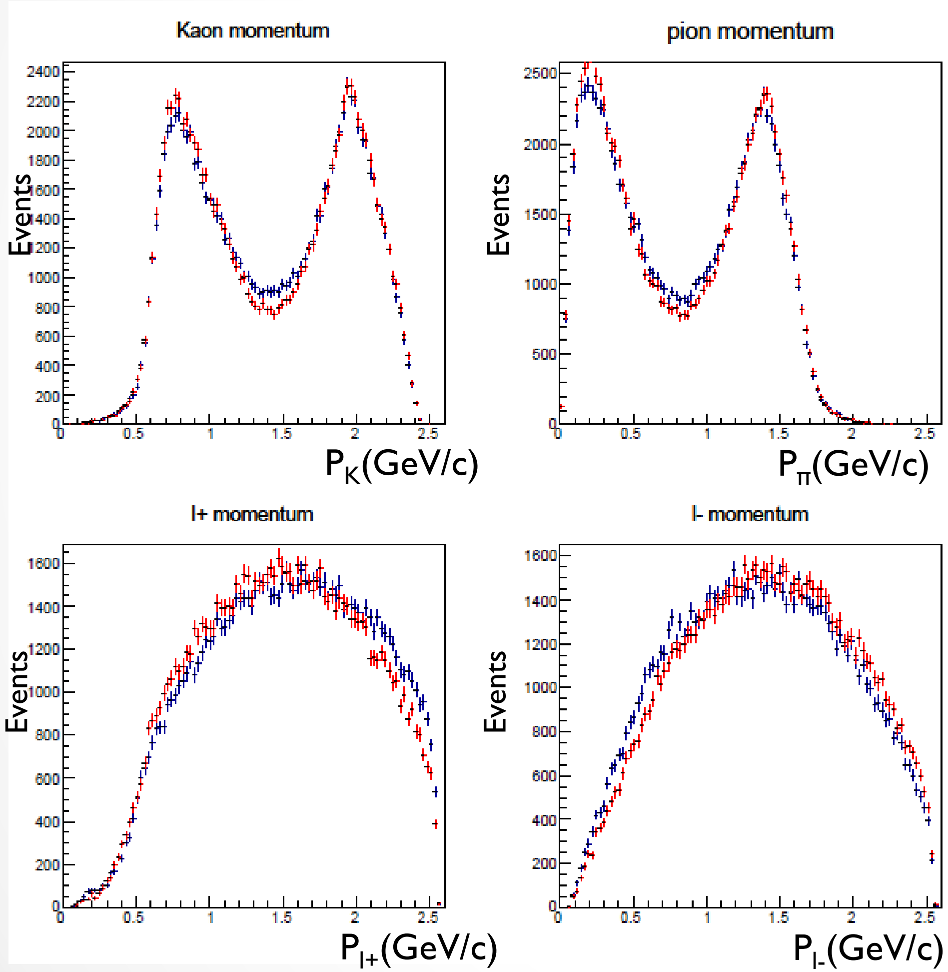


Low Recoil q2 14-19 GeV^2



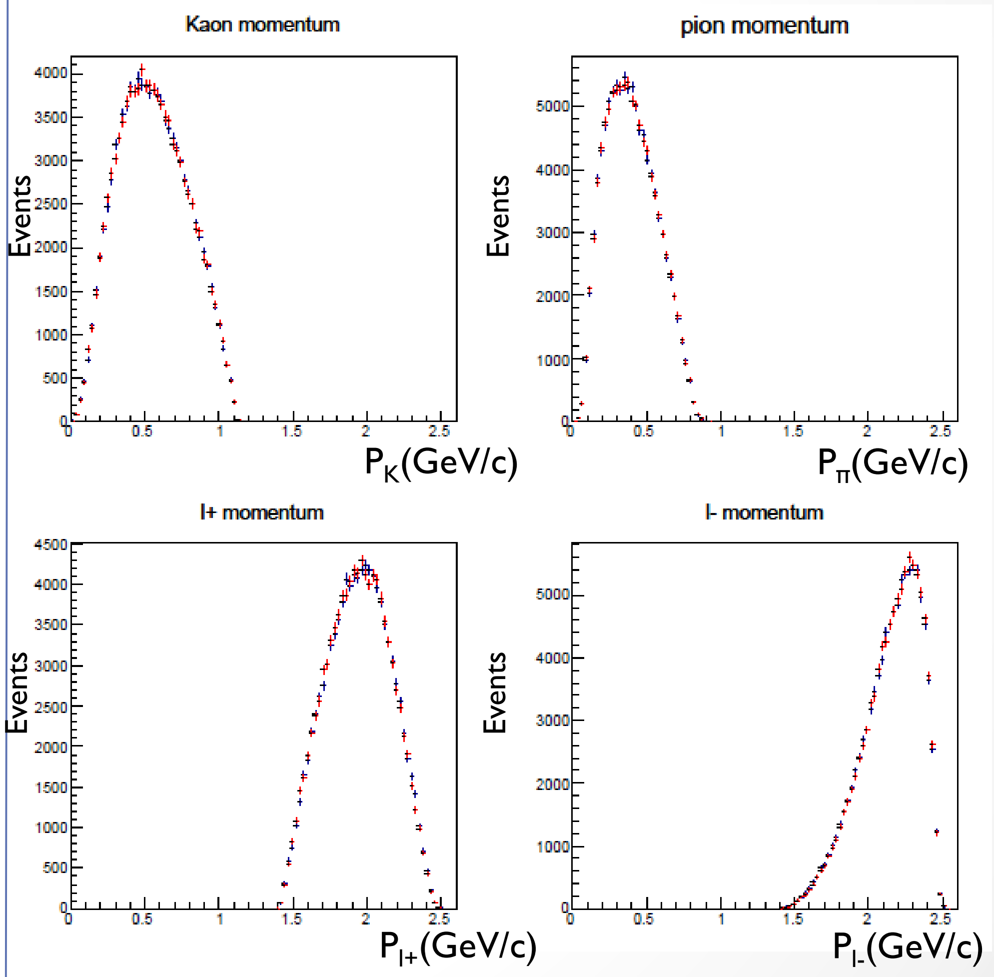
Large Recoil q2 1-6 GeV^2

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



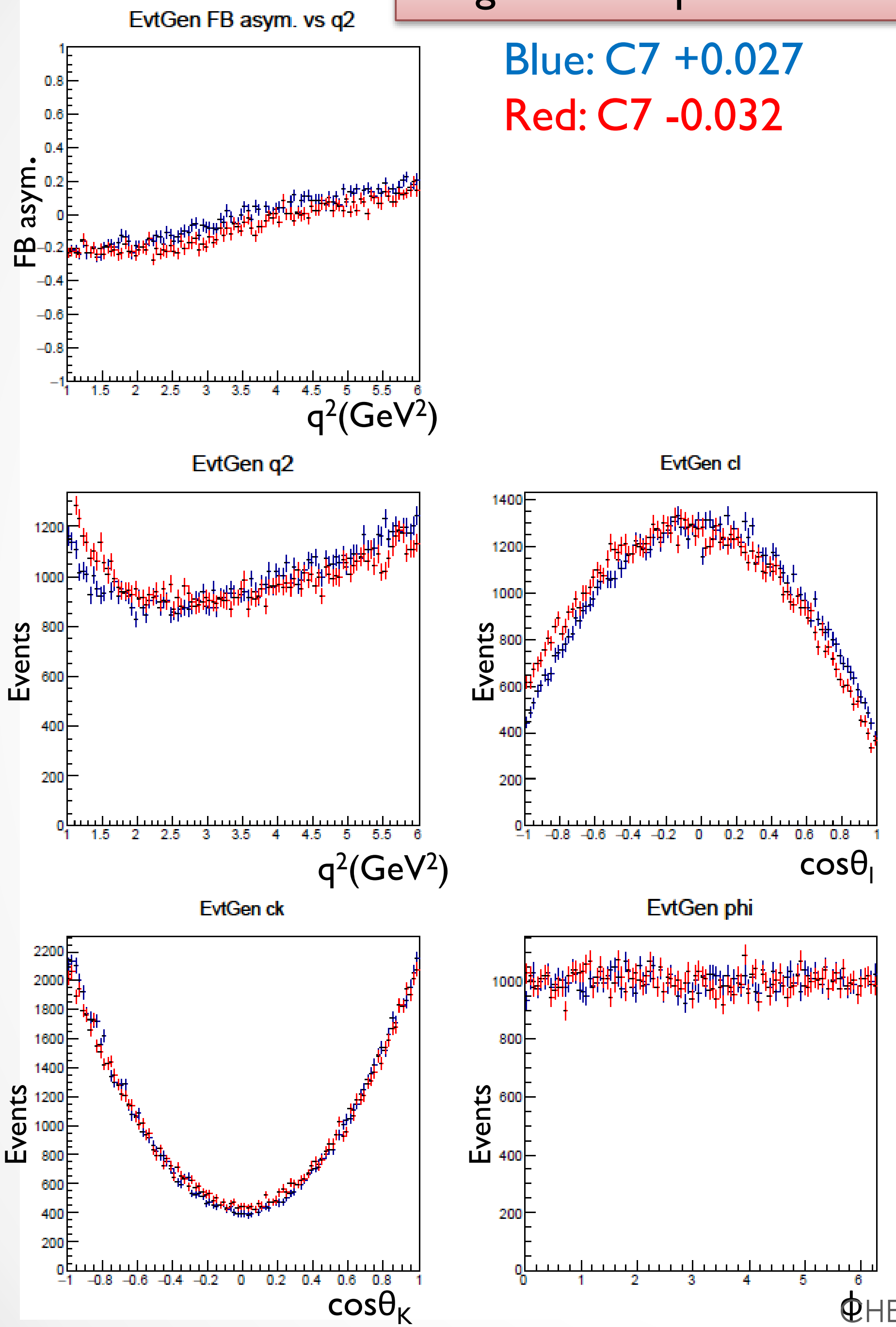
Low Recoil q2 14-19 GeV^2

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



Large Recoil q2 1-6 GeV²

Blue: C7 +0.027
Red: C7 -0.032



Low Recoil q2 14-19 GeV²

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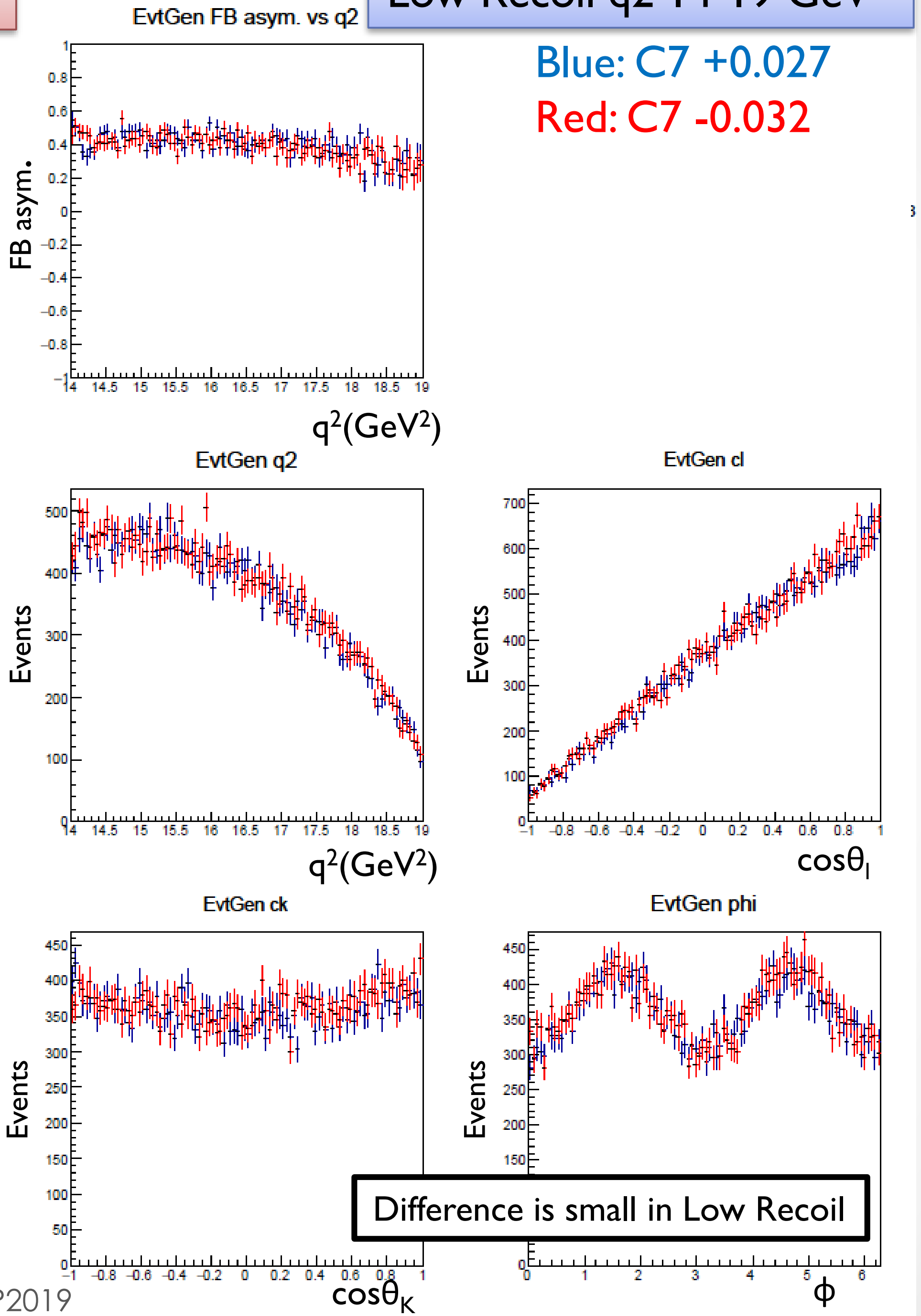
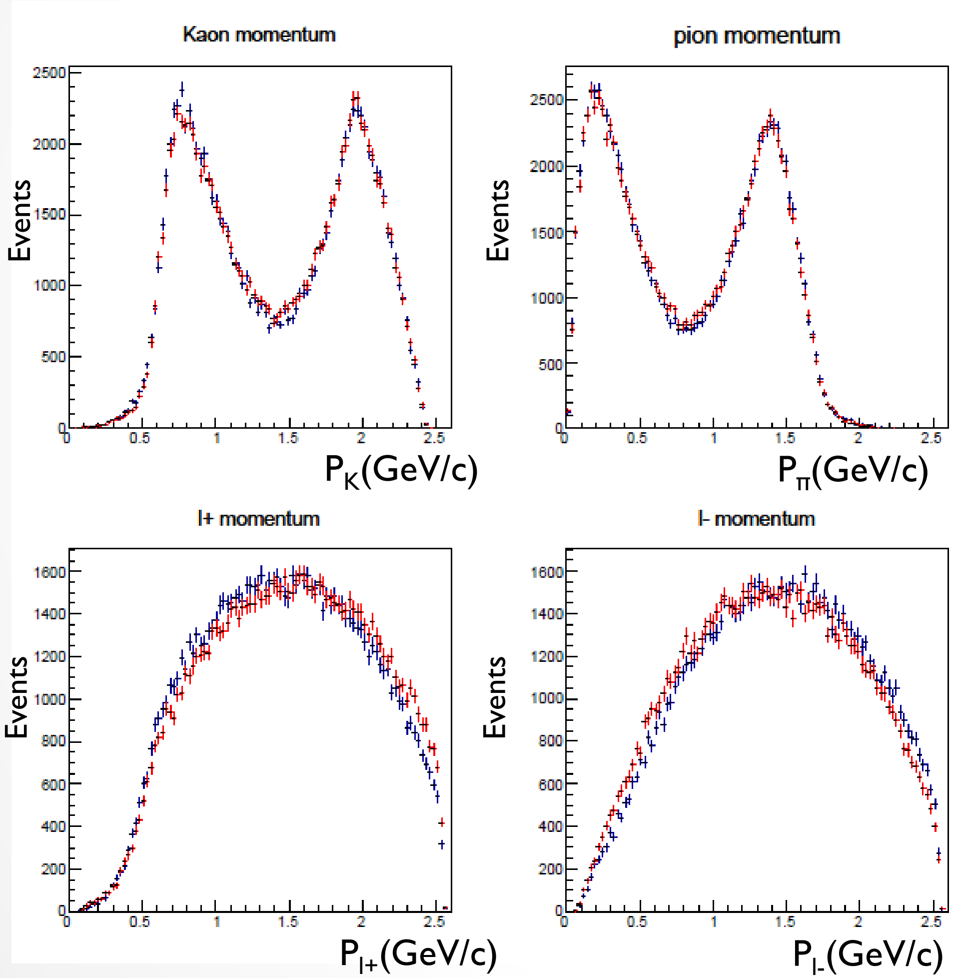


Difference is small in Low Recoil

Large Recoil q2 1-6 GeV^2

Blue: C7 +0.027

Red: C7 -0.032



Low Recoil q2 14-19 GeV^2

Blue: C7 +0.027

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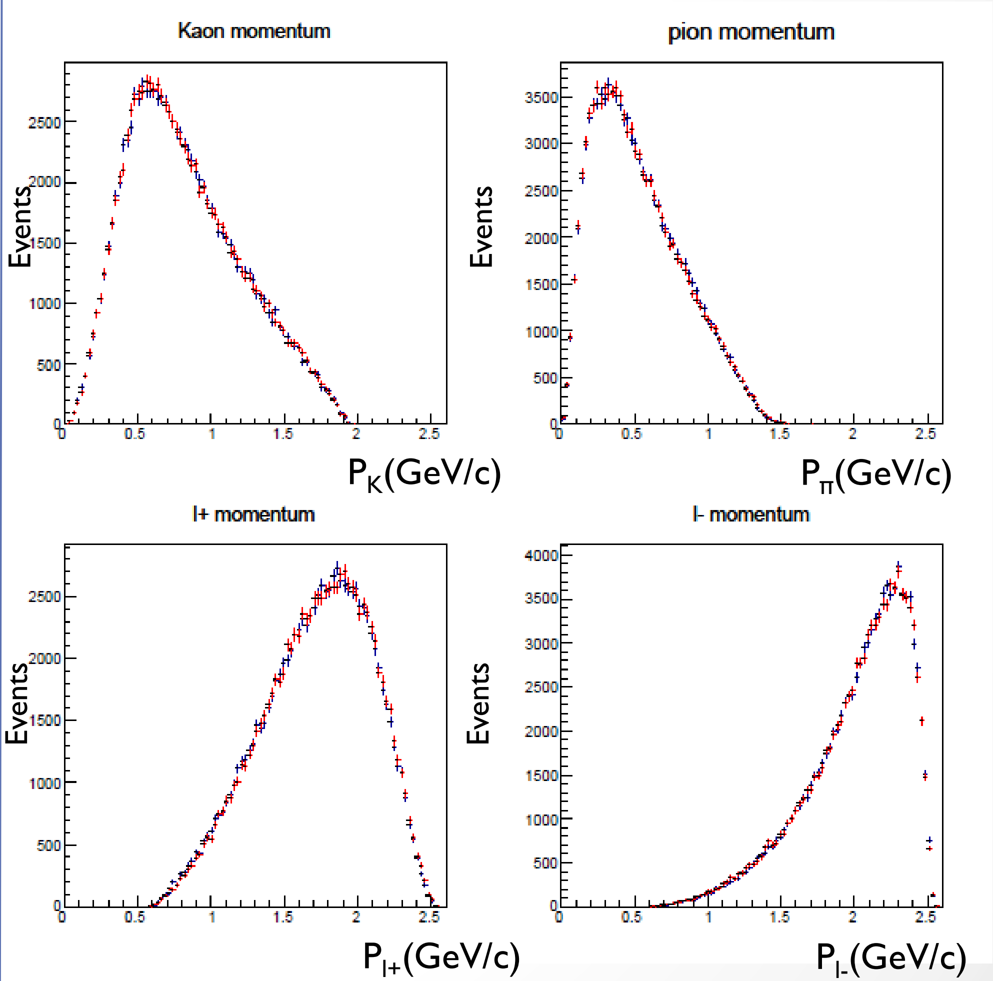

Wilson Coefficient for B→K*ll Decay in EOS

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

Qualified Name	Representation	Default Value
b->s::Im{c7'}	$\Im C_{7'}$	0.0
b->s::Im{c7}	$\Im C_{7}$	0.0
b->s::Re{c7'}	$\Re C_{7'}$	0.0
b->s::Re{c7}	$\Re C_{7}$	-0.33726473
b->s::c1	C_1	-0.29063621
b->s::c2	C_2	1.01029623
b->s::c3	C_3	-0.0061622
b->s::c4	C_4	-0.08730376
b->s::c5	C_5	0.00042854
b->s::c6	C_6	0.00115807
b->s::c8	C_8	-0.18288898
b->s::c8'	$C_{8'}$	0.0

K*ee

b->see::Im{c10'}	$\Im C_{10'}^{(e)}$	0.0
b->see::Im{c10}	$\Im C_{10}^{(e)}$	0.0
b->see::Im{c9'}	$\Im C_{9'}^{(e)}$	0.0
b->see::Im{c9}	$\Im C_{9}^{(e)}$	0.0
b->see::Im{cP'}	$\Im C_{P'}^{(e)}$	0.0
b->see::Im{cP}	$\Im C_{P}^{(e)}$	0.0
b->see::Im{cS'}	$\Im C_{S'}^{(e)}$	0.0
b->see::Im{cS}	$\Im C_{S}^{(e)}$	0.0
b->see::Im{cT5}	$\Im C_{T5}^{(e)}$	0.0
b->see::Im{cT}	$\Im C_{T}^{(e)}$	0.0
b->see::Re{c10'}	$\Re C_{10'}^{(e)}$	0.0
b->see::Re{c10}	$\Re C_{10}^{(e)}$	-4.16611761
b->see::Re{c9'}	$\Re C_{9'}^{(e)}$	0.0
b->see::Re{c9}	$\Re C_{9}^{(e)}$	4.27342842
b->see::Re{cP'}	$\Re C_{P'}^{(e)}$	0.0
b->see::Re{cP}	$\Re C_{P}^{(e)}$	0.0
b->see::Re{cP'}	$\Re C_{P'}^{(e)}$	0.0
b->see::Re{cP}	$\Re C_{P}^{(e)}$	0.0
b->see::Re{cS'}	$\Re C_{S'}^{(e)}$	0.0
b->see::Re{cS}	$\Re C_{S}^{(e)}$	0.0
b->see::Re{cT5}	$\Re C_{T5}^{(e)}$	0.0

K*μμ

b->smumu::Im{c10'}	$\Im C_{10'}^{(\mu)}$	0.0
b->smumu::Im{c10}	$\Im C_{10}^{(\mu)}$	0.0
b->smumu::Im{c9'}	$\Im C_{9'}^{(\mu)}$	0.0
b->smumu::Im{c9}	$\Im C_{9}^{(\mu)}$	0.0
b->smumu::Im{cP'}	$\Im C_{P'}^{(\mu)}$	0.0
b->smumu::Im{cP}	$\Im C_{P}^{(\mu)}$	0.0
b->smumu::Im{cS'}	$\Im C_{S'}^{(\mu)}$	0.0
b->smumu::Im{cS}	$\Im C_{S}^{(\mu)}$	0.0
b->smumu::Im{cT5}	$\Im C_{T5}^{(\mu)}$	0.0
b->smumu::Im{cT}	$\Im C_{T}^{(\mu)}$	0.0
b->smumu::Re{c10'}	$\Re C_{10'}^{(\mu)}$	0.0
b->smumu::Re{c10}	$\Re C_{10}^{(\mu)}$	-4.16611761
b->smumu::Re{c9'}	$\Re C_{9'}^{(\mu)}$	0.0
b->smumu::Re{c9}	$\Re C_{9}^{(\mu)}$	4.27342842
b->smumu::Re{cP'}	$\Re C_{P'}^{(\mu)}$	0.0
b->smumu::Re{cP}	$\Re C_{P}^{(\mu)}$	0.0
b->smumu::Re{cS'}	$\Re C_{S'}^{(\mu)}$	0.0
b->smumu::Re{cS}	$\Re C_{S}^{(\mu)}$	0.0
b->smumu::Re{cT5}	$\Re C_{T5}^{(\mu)}$	0.0
b->smumu::Re{cT}	$\Re C_{T}^{(\mu)}$	0.0