# $B \rightarrow X_s \nu \bar{\nu}$ study at Belle2

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### Introduction

•  $B \rightarrow X_s \nu \bar{\nu}$  is theoretically clean and it can give constraints on Wilson coefficient



• MC samples

Background MC sample: official background  $1 ab^{-1}(\Upsilon(4S) \rightarrow B^+B^-, B^0\overline{B^0}, u\bar{u}, d\bar{d}, s\bar{s}, c\bar{c})$ 

Signal sample: privately produced signal samples

- $B^+ \rightarrow K^+ \nu \bar{\nu}$ : 10M
- $B^+ \rightarrow K^{*+} \nu \bar{\nu}$ : 10M
- $B^+ \rightarrow X_s \nu \bar{\nu}$ : 50M
- $B^0 \rightarrow K^0 \nu \bar{\nu}$ : 10M
- $B^0 \rightarrow K^{*0} \nu \bar{\nu}$ : 10M
- $B^0 \rightarrow X_s \nu \bar{\nu}$ : 50M
- Skimming was based on FEI

 $M_{bc}^{tag} > 5.24~{\rm GeV}$ 

 $|\Delta E^{tag}| < 0.2 \text{ GeV}$ 

signal probability > 0.001

Signal MC samples were produced separately

 $B \to K \nu \bar{\nu}$ 

 $B\to K^*\nu\bar\nu$ 

 $B \to X_s \nu \bar{\nu} \ (M_{Xs} > 1.1 \ {\rm GeV})$ 

There ratio between modes was determined by theoretical value (reference is in the next slide)

• I used Fermi motion model to produce  $B \to X_s \nu \overline{\nu}$  samples

This model is also used in  $B \rightarrow X_s ll$  model of evtgen

In Fermi motion model, quarks inside B meson has velocity, which follows Gaussian distribution After producing  $X_s$ , hadronization is done by PYTHIA

• Decay was simulated by evtgen. Detector simulation was done by Geant4

- Form factor at  $B \rightarrow K \nu \bar{\nu}$  [arXiv:1409.4557v2]
- Form factor at  $B \rightarrow K^* \nu \bar{\nu}$  [arXiv:1503.05534v3]
- Decay distribution  $B \rightarrow X_s \nu \overline{\nu}$  [arXiv:1509.06248v2]

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}s_b} = m_b^5 \frac{\alpha^2 G_f^2}{128\pi^5} |V_{ts}^* V_{tb}|^2 \kappa(0) (|C_L^\nu|^2 + |C_R^\nu|^2) \lambda^{1/2} (1, \tilde{m}_s^2, s_b) \\ \times \left[ 3s_b (1 + \tilde{m}_s^2 - s_b - 4\tilde{m}_s \frac{Re(C_L^\nu C_R^{\nu*})}{|C_L^\nu|^2 + |C_R^\nu|^2}) + \lambda(1, \tilde{m}_s^2, s_b) \right] \quad \& s_b = \frac{q^2}{m_b^2}$$

- Parameters for  $B \rightarrow X_S \nu \bar{\nu}$  decay distribution ( $m_b = 4.8 \text{ GeV}$ ,  $m_s = 0.2 \text{ GeV}$ ) Ali, Ahmed, et al. "Power corrections in the decay rate and distributions in B $\rightarrow$  X s I+ I- in the standard model." *Physical Review D* 55.7 (1997): 4105.
- Fermi motion model for non-resonant  $B \rightarrow X_s \nu \bar{\nu}$  decay

Ali, Ahmed, et al. "Power corrections in the decay rate and distributions in  $B \rightarrow X \text{ s I+ I-}$  in the standard model." *Physical Review D* 55.7 (1997): 4105.

- Parameter for fermi motion model ( $p_F = 0.461$ ) [arXiv:1909.12524v3]
- Branching ration of  $B \to K \nu \bar{\nu}, B \to K^* \nu \bar{\nu}$ , and  $B \to X_s \nu \bar{\nu}$  [arXiv:1409.4557v2]



- Blue point: my MC sample (normalization: Sum of entry = 3.98)
- Red band: Theoretical calculation [arXiv:1409.4557] band indicates uncertainties from form factor and parameters

 $\stackrel{\text{\tiny (2)}}{\times} q^2 = (p_\nu + p_{\overline{\nu}})^2$ 



- Blue point: my MC sample (normalization: Sum of entry = 9.19)
- Red band: Theoretical calculation [arXiv:1409.4557] band indicates uncertainties from form factor and parameters



- Left histogram: my MC sample  $(m_b = 4.8 \text{ GeV}, m_s = 0.2 \text{ GeV})^{\ddagger}$ Red line: theoretical calculation including resonant decay  $(m_b = 4.68 \text{ GeV}, m_s = 0.1 \text{ GeV})$  [arXiv:1509.06248]
- Right histogram: Mass distribution of my MC sample







### Particle selection criteria

Particle	Selection Criteria
Charged tracks	$dr < 0.5  ext{ cm},  dz  < 2  ext{ cm}$
$K^{\pm}$	$PID_K > 0.6$ , nCDCHits $> 20$
$\pi^{\pm}$	$PID_{\pi} > 0.6$ , nCDCHits > 20
$K^0$	Reconstructed from two oppositely charged tracks with the vertex fit
	significanceOfDistance > 50, 0.4876 < M < 0.5076 GeV
	$17^{\circ} <  heta_{\gamma} < 150^{\circ}$ , clusterNHits $> 1.5$ and
17	[clusterReg == 1 and $E > 0.08$ GeV] or
Ŷ	[clusterReg == 2 and $E > 0.03$ GeV] or
	[clusterReg == 3 and $E > 0.06$ GeV]
$\pi^0$	Reconstructed from two $\gamma's$
π.	$0.12 < M_{\gamma\gamma} < 0.145$ GeV, $-1.5 < \Delta \phi_{\gamma\gamma} < 1.5$ rad, $p_{\pi^0} > 0.4$ GeV

 Full event interpretation (FEI) was used to reconstruct tag side of B meson hadronic tag was used



I reconstruct 20 decay modes of signal side (sum of exclusives method)
B<sup>+</sup> → K<sup>+</sup>νν̄ B<sup>+</sup> → K<sup>+</sup>π<sup>0</sup>νν̄ B<sup>+</sup> → K<sup>0</sup><sub>S</sub>π<sup>0</sup>νν̄ B<sup>+</sup> → K<sup>0</sup><sub>S</sub>π<sup>+</sup>π<sup>0</sup>νν̄ B<sup>+</sup> → K<sup>+</sup>π<sup>-</sup>π<sup>+</sup>π<sup>0</sup>νν̄
B<sup>+</sup> → K<sup>0</sup><sub>S</sub>π<sup>+</sup>π<sup>-</sup>π<sup>+</sup>νν̄ B<sup>+</sup> → K<sup>+</sup>K<sup>-</sup>K<sup>+</sup>νν̄ B<sup>0</sup> → K<sup>0</sup><sub>S</sub>νν̄ B<sup>0</sup> → K<sup>+</sup>π<sup>-</sup>νν̄ B<sup>0</sup> → K<sup>0</sup>π<sup>0</sup>νν̄
B<sup>0</sup> → K<sup>+</sup>π<sup>-</sup>π<sup>0</sup>νν̄ B<sup>0</sup> → K<sup>0</sup><sub>S</sub>π<sup>+</sup>π<sup>-</sup>νν̄ B<sup>0</sup> → K<sup>+</sup>π<sup>-</sup>π<sup>+</sup>π<sup>-</sup>νν̄ ··· and more···

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Number of event

Selection	SIGNAL	CHG	MIX	UUBAR	DDBAR	SSBAR	CHARM					
Generated	18889	$0.3 \ ab^{-1}$										
Skimed	240.21	$2.31 \cdot 10^{7}$	$1.74 \cdot 10^{7}$	$4.85 \cdot 10^{7}$	$1.17 \cdot 10^7$	$9.67 \cdot 10^{6}$	$5.59 \cdot 10^{7}$					
Reconstructed & preselection	119.18	$4.33 \cdot 10^{6}$	$2.90\cdot 10^6$	$5.84 \cdot 10^{6}$	$1.35 \cdot 10^{6}$	$2.11 \cdot 10^{6}$	$1.01 \cdot 10^{7}$					
Number of remaining clean track	76.86	$2.01\cdot 10^5$	$1.30\cdot 10^5$	$3.89 \cdot 10^{5}$	94368	$2.04\cdot 10^5$	7.25 · 10 <sup>5</sup>					
$0.297 < \theta_{missing} < 2.618$	72.16	$1.77\cdot 10^5$	$1.15\cdot 10^5$	$3.20 \cdot 10^{5}$	78253	$1.80\cdot 10^5$	$6.23 \cdot 10^{5}$					
$0.5 < p_{sig} < 2.96$	69.02	$1.62 \cdot 10^{5}$	$1.04 \cdot 10^{5}$	$3.00\cdot 10^5$	73631	$1.72 \cdot 10^{5}$	$5.83 \cdot 10^{5}$					
$M_{bc}^{tag} > 5.27$	55.39	70432	44147	$1.05 \cdot 10^{5}$	25522	60966	$1.99 \cdot 10^{5}$					
D veto	55.17	67187	42039	$1.01 \cdot 10^{5}$	24611	59432	$1.93 \cdot 10^{5}$					
MVA	4.65	70	25	5	2	1	6					
BCS	4.65	70	25	5	2	1	6					

% Signal sample is scaled by 0.3  $ab^{-1}$ 

 $\therefore$  Clean track: dr < 0.5 cm, |dz| < 2 cm

% Best candidate selection was done by SignalProbability

#### • D veto

Get mass from all combination of  $B_{sig}$  whose charge is 0 or  $\pm 1$ . And reject if the mass is in D meson mass window



5.27

5.28

5.26

5.3 M<sub>bc</sub> [GeV]

5.29

0 5.24

5.25



#### • I used 15 variables for TMVA

Variables	Explanation
thrustBm	magnitude of the thrust axis
cosTBTO	cosine of angle between thrust axis of the $B_{tag}$ and thrust axis of ROE
hso00, hso22, hso24, hoo1	KSFW variables
$ heta_{tag}$	$\theta$ of $B_{tag}$ in CMS frame
SignalProbability	Signal probability of $B_{tag}$ from FEI
chiProb	$\chi^2$ probability from vertex fit of $B_{tag}$
$ heta_{miss}$	$\theta$ of missing momentum
nRemainingTracksInEvent	The number of remaining raw tracks
harmonicMomentThrust1	Harmonic moment of the 1st order calculated with respect to the thrust axis
cleoConeThrust0	0th Cleo cone calculated with respect to the thrust axis
MsquaredBsig_op1	$(p_{sig} + p_{miss})^2$ at CMS frame
$\Delta E^{tag}$	$\Delta E  ext{ of } B_{tag}$

I tried to select variables which had a low correlation with  $E_{ecl}$ 

#### • I trained 4 BDTs

```
signal VS continuum & M_{Xs} < 1.1 \text{ GeV}
```

```
signal VS B\overline{B} & M_{Xs} < 1.1 \text{ GeV}
```

signal VS continuum &  $M_{Xs} > 1.1 \text{ GeV}$ 

signal VS  $B\overline{B}$  &  $M_{Xs} > 1.1 \text{ GeV}$ 

• Each signal candidate has two BDT outputs

									C	onti	nuu	m si	uppi	ress	ion						
		0.3	0.31	0.32	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.4	0.41	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49
	0.49	0.3	0.3	0.3	0.3	0.3	0.29	0.29	0.29	0.29	0.29	0.29	0.28	0.28	0.28	0.27	0.29	0.29	0.28	0.28	0.27
	0.48	0.33																			0.33
	0.47	0.33								0.31	0.31							0.31		0.31	
	0.46	0.35	0.36	0.36	0.36	0.35	0.35	0.35	0.34												
	0.45	- 0.38	0.39	0.38	0.38	0.38	0.37	0.37	0.36	0.37	0.36	0.37	0.36	0.36	0.36	0.35	0.35				
	0.44	- 0.43	0.44	0.43	0.43	0.42	0.43	0.42	0.42	0.42	0.41	0.42	0.41	0.41	0.4	0.39	0.39	0.38	0.38	0.37	0.37
	0.43	- 0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.43	0.44	0.43	0.43	0.42	0.42	0.42	0.41	0.4	0.39	0.39	0.38	0.37
B	0.42	- 0.47	0.48	0.47	0.47	0.48	0.48	0.49	0.48	0.48	0.48	0.48	0.47	0.46	0.46	0.45	0.44	0.42	0.43	0.41	0.4
N Bl	0.41	- 0.48	0.49	0.48	0.48	0.49	0.49	0.5	0.49	0.48	0.48	0.48	0.47	0.47	0.46	0.45	0.45	0.43	0.43	0.41	0.4
ldn	0.4	0.49	0.5	0.49	0.49	0.5		0.52			0.51		0.5	0.49	0.49	0.48	0.48	0.46	0.47	0.44	0.44
ores	0.39	0.51																0.49	0.5	0.47	0.46
ssio	0.38	0.51						0.54		0.55	0.54		0.52						0.52	0.49	0.48
u	0.37	0.5								0.54	0.54	0.54							0.53	0.5	0.49
	0.36	0.52				0.54	0.54	0.55	0.55	0.56	0.56	0.56	0.55	0.56	0.56	0.55	0.55	0.54	0.55	0.52	
	0.35	0.51								0.54	0.54			0.55	0.55	0.55	0.54		0.55	0.52	
	0.34	0.51								0.54	0.54	0.54	0.54	0.55	0.56	0.55	0.54		0.54	0.51	0.49
	0.33	0.51										0.54		0.54	0.54			0.5	0.52	0.49	0.47
	0.32	0.5												0.51		0.5	0.5	0.5		0.49	0.47
ן	0.31	0.51													0.5	0.49	0.49	0.47	0.49	0.48	0.47
	0.3	0.51							0.49	0.49	0.49	0.49	0.48	0.48	0.48	0.47	0.47	0.46	0.47	0.46	0.46

 $B\overline{B}$ 

⊷ FOM plot for  $M_{Xs} < 1.1 \, \text{GeV}$  and  $E_{ecl} < 2 \text{ GeV}$  region

> • FOM  $\frac{S}{\sqrt{S+B}}$ Signal is scaled by  $0.3 \ ab^{-1}$

• I select  $\mathcal{O}_{B\bar{B}} > 0.35$  $\mathcal{O}_{q\bar{q}} > 0.43$ 

- 0.30

- 0.35

- 0.50

- 0.45

- 0.40

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	0.3 -	0.17	0.17	0.17	0.17	0.17		0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.16
	. 0.31	0.17	0.17	0.17	0.17	0.17			0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.16	0.16
	0.32 -	0.17	0.17		0.17						0.17		0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.16	0.16
	0.33 -	0.17									0.17			0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.16
	0.34 -	0.17												0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.16
	0.35 -	0.17												0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.16
	0.36 -			0.18		0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.17	0.17	0.17		0.17	0.17	0.17
J	0.37 -						0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18						0.17	
Siot	0.38 -						0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18							
res	0.39 -	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19	0.19	0.18	0.18					0.18		
Ipp	0.4 -	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19	0.19	0.18	0.18	0.18						
SU SU	0.41 -	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.17						
$B\bar{B}$	0.42 -	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18					0.17	0.17		0.17
	0.43 -		0.17				0.18			0.18		0.17	0.17	0.17	0.16	0.16	0.17	0.17	0.16	0.16	0.16
	0.44 -	0.18	0.18	0.18	0.18	0.18	0.19	0.19	0.18	0.18	0.18	0.18	0.18	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.18
	0.45 -	0.19	0.18	0.19	0.19	0.19	0.19	0.19	0.19	0.18	0.18				0.17		0.18		0.18	0.17	
	0.46-	0.18	0.18	0.18	0.18	0.18	0.18	0.19	0.18	0.18		0.17	0.17	0.17	0.17	0.17	0.18		0.17	0.17	0.17
	0.47 -	0.19	0.18	0.19	0.19	0.19	0.19	0.2	0.19	0.19	0.19	0.18	0.18	0.18	0.18	0.18	0.19	0.18	0.18	0.17	0.17
	0.48-	0.17	0.17	0.18	0.18	0.18	0.18	0.19	0.19	0.18	0.18	0.18			0.17	0.18	0.18	0.18	0.17	0.17	0.16
	0.49-	0.17	0.16	0.17	0.18	0.19	0.19	0.21	0.2	0.2	0.2	0.19	0.19	0.19	0.19	0.2	0.23	0.22	0.22	0.21	0.21
		0.3	0.31	0.32	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.4	0.41	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49
									C	cont	inuu	im s	upp	press	ion						

← FOM plot for  $M_{Xs} > 1.1 \text{ GeV}$  and  $E_{ecl} < 2 \text{ GeV}$  region

• FOM  $\frac{S}{\sqrt{S+B}}$ Signal is scaled by 0.3  $ab^{-1}$ 

• I select  $\mathcal{O}_{B\bar{B}} > 0.47$  $\mathcal{O}_{q\bar{q}} > 0.44$ 

- 0.17

- 0.22

- 0.21

- 0.20

- 0.19

- 0.18

# Reconstruction and analysis (Ongoing)



• I tried to do a fitting with a histogram PDF It overestimate the number of signal

#### • 2D fit?

small number of signal events are spread

Also, there is no good variable which separate signal and background

# Reconstruction and analysis (Ongoing)

A RooPlot of "number of signal events"



A RooPlot of "number of signal events Error"



1000 toy MC study
 pull distribution looks ok

# Summary

• MC signal samples were produced and the validation was conducted

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- FEI was used to reconstruct tag side B meson
- After MVA, there are still significant amount of background

# Plan





Back up



 $\uparrow B^+ \to K^{*+} \nu \bar{\nu}$  (set width of  $K^{*+}$  to be zero)