

Korea Institute of Science and Technology Information

# The Automatic Particle Reconstruction with Machine Learning at e<sup>+</sup>e<sup>-</sup> Collider

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- Introduction to  $B^0 \to \ell^{\pm} \tau^{\mp}$
- Application & Results

#### Summary

## Introduction: $e^+e^-$ Collider

### $e^+e^-$ Collider & B Meson Analysis

Characteristics of  $e^+e^-$  colliders for *B* meson analysis

• Focusing  $e^+e^-$  beams that CM energy goes near 10.58GeV, the mass of Y(4S) (Upsilon 4S)

Experiment	Location	e- beam energy	e+ beam energy
BaBar[1]	SLAC, USA	9.0 GeV	3.1 GeV
Belle[2]	KEK, Japan	8.0 GeV	3.0 GeV
Belle II[3]	KEK, Japan	7.0 GeV	4.0 GeV

- Upsilon(4S) creation from  $e^+e^-$  collision : decays to  $B\overline{B}$  with 96% branching ratio
- Clean event : Only 2 B mesons (and background particles like cosmic ray) are in the event
- $\Rightarrow$  The best condition to study *B* mesons



#### How to Reconstruct B?

*B* meson analysis : reconstructing B inclusively or exclusively

- B meson decays to final state particles :  $e^{\pm}$ ,  $\mu^{\pm}$ ,  $\pi^{\pm}$ ,  $K^{\pm}$ ,  $\gamma$ 
  - Reconstruction of B meson should be done.
- Inclusive : signal-side B reconstruction only
- Exclusive : 1) tag-side (B<sub>tag</sub>) 2) signal-side
   B reconstruction
- It is possible because B decay events from  $e^+e^-$  and Y(4S) are 'clean'



### Difficulties of B Tagging

There are many *B* meson decays.

- 500 for  $B^+$ ,  $B^0$  each
- Since not tagged decay channels are excluded, the selection of tagging mode is important.
  - Signal efficiency is always important!

					Kor K.			
				~	And Kont			
	Li stanic modes	$(10.99 \pm 0.28)$	)%	~ P34	King King			
<ul> <li>Semileptonic and</li> </ul>	d leptonic ma	$(10.8 \pm 0.4)^{\circ}$	6	~ P <sub>248</sub>	n's-			
$\Gamma_1 = \ell^+ \nu_\ell X$		(1.65 ± 0.2)	$) \times 10^{-3}$	~ P349	n'n			
$\Gamma_2 = e^+ \nu_e J$	Xe	(1.6 + 0.7)	%	~ P <sub>300</sub>	****(892)+ P'10		(2.37±0.00)	
$\Gamma_{a} = \ell^{+} \nu_{\ell}$	X <sub>s</sub>	(9.0 ± 0.0)	2310	$\sim P_{26q}$	n' 10 (1430) +		(1.29 ± 0.00) ×	10-4
D. DE+	$\nu_{\ell}X$	(2.30 ± 0.0	191 191	P362	" K2(1430)+		(7.04 ± 0.00) × 1	0-3 2614
D°t	l+ ve	$(7.7 \pm 2.5)$	225	8 P <sub>353</sub>	4A ·		$(4.8^{+1.8})$ × 10	-8 2616
Γ <sub>5</sub>	7 <sup>+</sup> 9 <sub>7</sub>	$(5.58 \pm 0)$	.22)% 183	39 <i>P</i> <sub>364</sub>	<sup>n*</sup> (892)+		(5.2 ± 2 1)	2520
Г6 Д	(0007) <sup>0</sup> E <sup>+</sup> VI	(1.88±	).20)% 23	06 F <sub>355</sub>	6(1430)+		(28±05)	2430
Γ <sub>7</sub> D	$(2007)^0 \pi^+ V_T$	(4.4±0	$(.4) \times 10^{-3}$	P356	(1430)+		(2.4 ± 0.0) × 10-5	-42 V
$\Gamma_8$ D	(2001) .	(2.5±	$(0.5) \times 10^{-3}$	06' F <sub>307</sub> 7(129)	)K+ × B( p(10)		(1.93 ± 0 × 10-6	224
Γ <sub>9</sub> Ι	$D^-\pi^+\ell^+\nu_\ell$ $\overline{D}^0_0 \to D^-\pi^+$	(1.53 :	$\pm 0.16) \times 10^{-3}$	P358 7(1405)	K+ × B( n(1295) → ŋnn)		$(1.8 \pm 0.7) \times 10^{-3}$	S=1.7 2500
$\Gamma_{10}$	$D_0(2420) \in \mathcal{D}_\ell^+ \to D^-\pi^+$	(1.85	± 0.25)%	Г <sub>350</sub> 7(1405) А	× B( 1/1 + 1)		(9.1 ± 3 c)	250
$\Gamma_{11}$	$D_2(2460)^{*}\ell^{*}\nu_{\ell}$ , $D_2$	(4.0	$+ 0.4) \times 10^{-3}$	(1475)K	$\times B(n(1405) \rightarrow K^{\circ}K)$	(3	29+0s	- BLUE
T <sub>12</sub>	$D^{(*)} n \pi \ell^+ \nu_\ell (n \geq 1)$	(0.0	$(1.020) \times 10^{-3}$	F361 h(1285)K	$(1475) \rightarrow K^{*}K)$	<1	-47/×10-4	24
Pa	$D^{*-}\pi^{+}\ell^{+}\nu_{\ell}$ = -0 r	(3.0	10.00	$\Gamma_{362} = \Gamma_{1420} K^{+} \times$	BLACK	\$1.5	2	2414
T B	$D_1(2420)^0 \ell^+ \nu_\ell$ , $D_1 \to L$	n (93	1 1 1	$F_{363}$ $f_{1420}K^+ \times E$	· J1(1420) → mm ]	(1.38)	*× 10~6 (	1=90% 2405
L.14	$D_{1}^{'}(2430)^{0}\ell^{+}\nu_{\ell}, \overline{D}_{1}^{0} \rightarrow$	0° m (802) <sup>+</sup>	$P_{\rm a}$	$\phi(1680)K^+ \times Bl$	$(f_1(1420) \rightarrow K^*K)$	\$20	ass) × 10~s Q	=90%
$\Gamma_{15}$	$D_{2}^{*}(2460)^{0}\ell^{+}\nu_{\ell}$ , $D_{2}^{*0}$ -	Г98 D К (657) <sup>+</sup>	P.365	A(1500)K*	$(1680) \rightarrow K^*K)$	<2.9	10-0	2425
$\Gamma_{16}$	$D^0 \pi^+ \pi^- \ell^+ \nu_\ell$	$\Gamma_{99} = \frac{D_{CP}(-1)^{2-1}}{\kappa^{\alpha}(892)^{\dagger}}$	$\Gamma_{\rm ang}$	<i>∞K</i> +		541	Qag Qag	2407
$\Gamma_{37}$	$\mathcal{D}^{0} \rightarrow \pi^{-} t^{+} \mathcal{V} t$	$D_{CP(\pm 1)}R^{-(22-7)}$	$P_{367}$	<i>∞K</i> *(892)+		53.4	c Cl=901	2458
$\Gamma_{18}$	DR	$\Gamma_{100} = D^0 K^*(892)^*$	$P_{363}$	ω(Kπ);		(3.7 + 2 =)	5 CL=903	240
$\Gamma_{10}$	$D_{\lambda}^{(*)} = K^+ \ell^+ \nu_\ell$	$\overline{D}^0 K^+ \pi^+ \pi^-$	+ P <sub>300</sub>	$\omega K_0^*(1430)^+$		(6.5 ± 0 × 1	10-6 Cl=90%	221
$\Gamma_{20}$	$D_s^+ K^+ \ell^+ \nu_\ell$	$[K^{\dagger}\pi^{-}]_{D}K^{\dagger}\pi^{-}$	R I <sup>7</sup> 379	$\omega K_{2}^{*}(1430)^{+}$		< 7.4 ~ 10	-6	200-
Γ <sub>23</sub>	$D_s^{*-}K^+\ell^+\nu_\ell$	$\Gamma_{103}$ [ $K^-\pi^+$ ] $_D$ $K^+\pi^-$	π Γ <sub>371</sub>	40(980) + K*×B( a (a)		(2.8 + 0		250
Em	$\pi^0 \ell^+ \nu_\ell$	Γ104 Dep(+3)K <sup>+</sup> π <sup>-</sup> π	* F <sub>372</sub>	(980)° K+×B( ~ (980)+	m+)	(2.4 + 0	CL=90%	800
P	$\pi^0 e^+ \nu_e$	F100	Pan AC	$(892)^{0}\pi^{+} \rightarrow \eta$	<b>*</b> <sup>0</sup> )	(2.1 ± 0 - 0		X03
1 25	$\eta \ell^+ \nu_\ell$	Γ <sub>106</sub> D K <sup>-1,2</sup> 0	Pane A*(8)	92)+ <sub>27</sub> 0		$\leq 3.9 \sim 10^{-5}$		
1.24	$\eta' t^+ \nu t$	Г107 D' К' К (ССС)	Para K <sup>*</sup> π <sup>*</sup> n	rt.		< 2.5 × 10-0	222	
L.52	wt vi	$\Gamma_{108} = \overline{D}^0 \pi^+ \pi^+ \pi$	ta at Fan Ka	a+ nonne		(1.01 + 0	CL=90%	
$\Gamma_{26}$	and Par	$\Gamma_{100} = \begin{bmatrix} K^- \pi^+ & D \end{bmatrix}$	4(782)	K		$(6.8 \pm 0.08) \times 10^{-3}$	CL=90%	
$\Gamma_{27}$	T Betw	$\overline{D}^0 \pi^+ \pi^+ \pi$	nomen			(5.10 ± 0.5	264	
$\Gamma_2$	28 p C - C	$D^0 \pi^+ \rho^0$		(4.1	± 0,	(1.63+0.29) × 10-5	254-	
Г	29 2. 1 6 71	$\Gamma_{111} = \overline{D}^0 a_1$	$(1260)^{+}$	(1.2	$(5 \pm 0.22)  imes 10$	-and × 10-5	240-	
T	Γ20 ppℓ <sup>+</sup> νℓ	F112		(8	$2 \pm 1.4) \times 10^{-5}$	·· × 10~*	2400	
	n.	F113 D 012	$(0)^{-}\pi^{+}\pi^{+}$	(5	$(4 \pm 1.5) \times 10^{-4}$	2299	2500	
		F114 D (2010	- K <sup>+</sup> π <sup>+</sup>		$1.07 \pm 0.05) \times 10^{-3}$	2260	AND C	
		L <sup>112</sup> D. (5010)	$(2420)^{0}\pi^{+}$ , $\overline{D}_{1}^{0}  ightarrow D^{*}(2010)^{-\pi}$		$(1.57)$ $(1.57)$ $\times$ 10 <sup>-5</sup>			
		Γ116	1(mm)		(7.7 ± 0.4) × 10 <sup>-6</sup>		-	
		$\Gamma_{117}$ $D^-\pi^+$	r		$(6.1 \pm 2.4)$ × 10 <sup>-5</sup>			
		Pus D-K	$\pi^+$ $D^0 \rightarrow D^- \pi^+$		(2.32±0.23)	2278	3	
		Due I	$f_{0}(2300)^{0}K^{+}$ , $D_{0}^{-}$ $D^{-}\pi^{+}$		$(3.6 \pm 1.2) \times 10$	CL=90% 20 0	2	
		1.110	$D_2^*(2460)^0 K^+$ , $D_2^* \rightarrow D^- \pi^+$		$< 2.9 \times 10^{-6}$	2200	1	
		L <sup>130</sup>	$D_1^*(2760)^0 K^+$ , $D_1^{**} \rightarrow D^{-1}$		$(5.6 \pm 1.1)  imes 10^{-6}$	CL=90%	2	
		T <sub>121</sub>	* K <sup>o</sup>		$< 6.3  imes 10^{-7}$	CL=90% 2211		
		F 122	w Kta		$< 4.9 \times 10^{-7}$	1		
		Γ 123	$D^{*}(2460)^{0}K^{+}$ , $D^{*0}_{2} \rightarrow D^{+}\pi^{-}$					
		<b>F</b> 124	D3(art )					
		<b>F</b> 125	D+ K**					

### Difficulties of B Tagging

There are many *B* meson decays.

- 500 for  $B^+$ ,  $B^0$  each
- Since not tagged decay channels are excluded, the selection of tagging mode is important.
  - Signal efficiency is always important!

B daughters can be decayed with various channels.

• Need to consider for daughter's decay mode to reconstruct

More work for reconstruction of tagged B

- Decay channel: (seems) determined on collaboration group
- Anyway, reconstructing manually is not so easy..
- Not finished: quality control of tagged B

Then why doing exclusive B study?

						~	Kor K* modes				
<ul> <li>Semi</li> <li>         Γ<sub>1</sub> </li> </ul>	$\Gamma_{117}$	$D^{-}\pi^{+}$	$\pi^+$					(1.0	$7\pm0.0$	$(05)  imes 10^{-3}$	
$\Gamma_2$	C. More	Ĩ		$(9.6 \pm 0.7)\%$	2	310	200 7 Kolldan			( <i>4.37</i> ±0.08) ×	10-1
Γ <sub>3</sub> Γ <sub>4</sub> Γ <sub>5</sub>	$\Gamma_{49}$	$K^0_S \pi$	+			* 3 <sub>2</sub>	a	(1.5	$562\pm$	0.031)%	
Γ6 Γ7	$\Gamma_{50}$	$K_L^0 \pi$	+					(1.4	$46\pm0$	.05)%	
Γ <sub>8</sub> Γ <sub>9</sub> Γ	$\Gamma_{51}$	<i>K</i> <sup>-</sup> 2	$\pi^+$	A 495, 195		- <u>10</u> -		(9.3	$38 \pm 0$	.16)%	S=1.7 25
X	$\Gamma_{86}$	$\pi^+\pi^0$						(1.2	$247 \pm 0$	$(0.033) \times 10^{-10}$	) <sup>-3</sup>
	$\Gamma_{87}$	$2 \pi^+ \tau$	r=					(3.2	$27\pm0$	$(.18)  imes 10^{-3}$	3 3
	Γ <sub>15</sub>	$\overline{D}_{2}^{*}(2460)^{0}\ell^{+}\nu_{\ell}$ , $\overline{D}_{2}^{*0}$ -	Γ <sub>98</sub> D	$D_{CP(-1)}K^{*}(892)^{+}$		$\Gamma_{305} = \omega K^+$	$(1680) \rightarrow K^{*}K)$		< 2.9 × 10-0	Que	2407
	Γ <sub>17</sub>	$D^0 \pi^+ \pi^- \ell^+ \nu_\ell$	F90	$D_{CP(+1)}K^{*}(892)^{+}$	P.	308 ωK*(892)+			< 4.1 × 10-0	Quegos	8 2458
	$\Gamma_{15}$	$\overline{D}^{\prime 0}\pi^+\pi^-\ell^+\nu_\ell$	L100	$D^{0}K^{*}(892)^{+}$	Page	$\omega(K\pi)_{0}^{*}$		(3	3.4 × 10-6	CL=903	2420
	Γ.,9	$D_s^{(*)-} K^+ \ell^+ \nu_\ell$	L.101	$\overline{D}^0 K^+ \pi^+ \pi^-$	$P_{3m}$			(6.5	(±2.2)×10-	Q=90%	2420
	Γ <sub>20</sub>	$D_s^- K^+ \ell^+ \nu_\ell$	<b>F</b> 102	$K^{+}\pi^{-} l_{D} K^{+}\pi^{-}\pi^{+}$	$\Gamma_{370}$	$\omega K_{2}^{*}(1430)^{+}$		574	± 0.4) × 10-6		2344
	Γn	$D_s^{*-}K^+\ell^+\nu_\ell$	<b>Г</b> 103	$K^{-}\pi^{+} \ln K^{+}\pi^{-}\pi^{+}$	$P_{3\gamma_1}$	ao(980) + K <sup>a</sup> ×B( o (o		(2.8 +	× 10-6		×398
	E.a.	$\pi^0 \ell^+ \nu \epsilon$	<b>T</b> 104	$D_{CP(+3)}K^{+}\pi^{-}\pi^{+}$	P372	90(980)°K+×B( 0.00	$0)^+ \rightarrow \eta_{\pi^+}$	(24+0	(4) × 10-5	CL=90%	-3 <i>58</i>
	P.a.	$\pi^0 e^+ \nu_e$	$L^{100}$	TO KIK	P373	K*(892) <sup>0</sup> <sup>#+</sup>	1" -> ma" )	(21 ± 0.5	5) × 10-4	40	03
	N 20	$\eta \ell^+ \nu_\ell$	T 105	$D = \frac{1}{K} \frac{1}{K} (892)^{0}$	Fan A	(892) <sup>+</sup> 3 <sup>0</sup>		< 3.9 × 10	× 10-5		
	1.24	$\eta' \ell^+ \nu_\ell$	$\Gamma_{107}$	DKKK	P375	R R!		< 2.5 × 10		2770	
	125	wet ve	Γ 108	$D'\pi^+\pi^+\pi^-$	Para	TATAT DOM DIST.		(1.01 ± 0.00		CL=90%	
	Γ <sub>26</sub>	wat <sup>+</sup> w <sub>p</sub>	Γw	μ (K <sup>-</sup> π <sup>+</sup> 1D <sup>-</sup> m	1 4m	782) K+		(6.8±0.0)×	10-*	CL=90%	
	$\Gamma_{27}$	altyr	E	$D^{0}\pi^{+}\pi^{+}\pi^{-}$ that				(5.10±0.20) × 10	6	2560	
	$\Gamma_{28}$	++++++VI		$\overline{D}^{0}\pi^{+}\rho^{0}$			(4.1±0, 10)	(1.63+0.21) × 10	-4	2562	
	$\Gamma_{29}$			$D^{0}a_{1}(1260)$			$(1.35 \pm 0.22) \times 10^{-5}$	(6±9)×10-5		2600	
	L <sup>20</sup>	ppe et		$\overline{D}^{0}\omega\pi^{+}$			$(8.2 \pm 1.4) \times 10$	10 0		2609	
	η.			$D^*(2010)^- \pi^+ \pi^+$			$(8.4 \pm 1.5) \times 10^{-4}$	22	~	2558	
				$\Gamma_{114}$ D*(2010) <sup>-</sup> K <sup>+</sup> π <sup>+</sup>	a p:(2010) <sup>-</sup> π <sup>+</sup>		$(1.07\pm0.05) imes10^{-5}$	22	60		
				$\Gamma_{115} = D_1 (2420)^0 \pi^+$	$\overline{D}_{1}^{*} \rightarrow D^{*}(222.7)$		$(7.7\pm0.5) imes10^{-5}$		~		
				F116			$(6.1 \pm 2.4) \times 10^{-6}$				
				Γ107 D			$(2.32 \pm 0.23) \times 10^{-5}$				
				Γ <sub>118</sub> D K <sup>10</sup>	, $D_0^{*0}  ightarrow D^- \pi^+$		$(3.6 \pm 1.2) \times 10^{-6}$	0-90%	2278		
				F110 De(2000) <sup>0</sup> K	, $D_2^{*0}  ightarrow D^- \pi^+$		2.9 × 10 <sup>-6</sup>	Clarine	2260		
				T <sub>120</sub> D <sub>2</sub> (2400) <sup>1</sup>	$+$ , $D_1^{*0}  ightarrow D^- \pi^+$		< 1.1) × 10 <sup>-6</sup>	11 00%		2	
				F121 D <sub>1</sub> (2760) 1			(5.0 ± 1.1)	CD=90%	2211	>	
				Γ <sub>122</sub> D <sup>+</sup> K <sup>0</sup>			< 6.3 × 10	CL=90%			
				$D^+K^+\pi^-$	$D^{*0} \rightarrow D^+\pi^-$		< 4.9 × 10				
				D <sub>2</sub> (2460)	K, 102						
				D+ K*0							
				U1250							

#### Advantages of B Tagging

Advantages of exclusive B tagging

- Effective continuum suppression due to different event topologies
- Requiring no additional particles in event (Completeness)
- Accessing tagged *B* information and additional information for quality control
  - : optimized to research that invisible particles are included in the decay channel.



## Automatic B Tagging with MVA

#### Reconstructing B with Machine Learning

#### B tagging with MVA (MultiVariate Analysis)

- Automatically reconstructing tagged B mesons
- Applied at each particle reconstruction & identification
- Assigning a classifier to each decay channel
- Used MVA tools: BDT(for Belle II) and ANN(for Belle, Babar)



Schematic view of B tagging via  $B \rightarrow D\pi$  channel

	1. $D^+ \rightarrow K^- \pi^+ \pi^+$	4 D+ channel
	2. $D^+ \rightarrow K^- \pi^+ \pi^+ \pi^0$	- Each decay channe
•	3. D <sup>+</sup> $\rightarrow$ K <sup>-</sup> K <sup>+</sup> $\pi$ <sup>+</sup>	takes its classifier
	4. $D^0 \rightarrow K^- K^+ \pi^+ \pi^0$	



#### Training a Classifier for Final State Particle

Final state particles : 4 charged particles (e,  $\mu$ ,  $\pi$ , K) and gamma

- Reconstructed with subdetector information
- Charged particle (e,  $\mu$ ,  $\pi$ , K) : track information + PID information
- Photon : deposited energy, shape information from calorimeters + PID information
- Training sample condition
  - Precut: PID information (track) or energy (cluster)
  - Postcut: probability(>0.01) and rank (10 for charged, 20 for photon) of particle classifier



#### Training a Classifier for Intermediate Particles

Training for particles as a part of B<sub>tag</sub>

- Particle type :  $\pi^0$ ,  $K_S^0$ ,  $J/\psi$ ,  $D^0$ ,  $D^+$ ,  $D_S^+$ ,  $D^{0*}$ ,  $D^{+*}$ ,  $D_S^{+*}$
- Training variable : kinematic variables + vertex variables + classifier probabilities of the daughters
- Training sample condition
  - Precut :  $P_{daughter}$  product, mass difference ( $\Delta M$ ), released energy (for  $D^*$ )
  - Postcut : probability (> 0.001) and rank (10) of particle classifier



#### Training a Classifier for B Mesons

Final training for B mesons

- Training variables : kinematic variables + vertex variables + MVA probabilities of the daughters
- Not using an invariant mass (hadronic) or angular variables (semileptonic) for training
  - Avoiding high correlation of  $M_{bc}$  (hadronic) and  $\cos\theta_{B,D^{(*)}\ell}$  (semileptonic)
- Training sample condition
  - Precut : P<sub>daughter</sub> product
  - Postcut : B candidates with 20 highest probabilities



## Applying to $B^0 \rightarrow \ell^{\pm} \tau^{\mp}$ Decay

### Properties & Processes of $B^0 \rightarrow \ell^{\pm} \tau^{\mp}$ Decay



- Forbidden in the Standard Model
- Predicted to occur in 'beyond the Standard Model' theories
- The properties of the signal B
- $\,\circ\,$  Invisible particles (neutrino) from  $\tau$  decay
- Lack of signal mode for B reconstruction

#### Sample condition

- Signal: Belle MC samples,
  - One B meson should be decayed to  $\ell^\pm \tau^\mp$
- Background: Belle generic background MC
  - Generated events of B pair or quark jet pair based on the Standard model
- Best candidate selection of tagB
- tagB with the highest classifier output



Event selection after B tagging

### Application of B Tagging: Results

#### Result of B tagging[6] application

- 1% signal tagging efficiency
- 0.04% or lower background efficiency
- Tagging works:
  - High continuum suppression
  - Additional signal/background separation with classifier output

	Class	Signal	Backgrounds					
	Туре	$B^0 \to \ell^\pm \tau^\mp$	generic B	$e^+e^- \to q  \overline{q}$	rare B	$b  ightarrow u\ell v$		
Befor	re tagging	$40 \times 10^6$	$754 \times 10^6$	$2350 \times 10^{6}$	$5.66 \times 10^{6}$	$5.47 \times 10^{6}$		
After	$B^0 \to e^\pm \tau^\mp$	400,980	138,820	19,657	287	2,050		
tagging	$B^0 \to \mu^\pm \tau^\mp$	380,315	135,908	19,068	290	2,007		

Tagging efficiency for  $B \rightarrow \ell \tau$ 

🗖 е-τ 🔷 μ-τ





**KYUNGHO KIM** 

#### Summary

- $e^+e^-$  colliders: the best condition to study *B* mesons
  - Precise construction of Y(4S) and B pair production makes the best condition for analysis.
  - Suitable to apply *B* tagging due to clean event.
  - Using *B* tagging can take the advantage of continuum suppression, signal/background separation with completeness, and additional variables for quality control.

The steps and processes of automatic particle reconstruction are shown.

- Training with classifiers at each steps and each particles are done.
- Application to  $B^0 \rightarrow \ell^{\pm} \tau^{\mp}$  decay channel shows remarkable background suppression and signal/background separation.

## Thank you!

for listening my presentation!

#### References

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[3] Belle II collaboration, arXiv:1011.0352 [physics.ins-det] (2010).

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#### Steps for Event Simulation

B meson decay at collider

- *B* mesons will be decayed to various decay channel.
- Usually *B* daughters will be decayed to other particles.
  - $\pi^0$  meson: mean lifetime  $8.43 \times 10^{-17} s$ , decay to 2  $\gamma$  with 98.82% probability
- Any particle will be decayed to stable particle:  $e^{\pm}$ ,  $\mu^{\pm}$ ,  $\pi^{\pm}$ ,  $K^{\pm}$ ,  $\gamma$

Simulation of detector-based *B* meson analysis (at Belle)

- Decay mode information is used to randomly generate tables (.gen) with event generation toolkit (EvtGen[4]).
- From the generation table, detector simulation with GEANT3[5] calculates the interaction between particles and variables.
- Simulation result (.mdst) is constructed from detector simulation.
  - Simulation results are saved same form as the data detected from detector.
  - Particles will be reconstructed from simulation results.



I	Particle type	Training input	Training condition		
Final state particles	Charged particles ( <i>e</i> , μ, π, <i>K</i> )	track information, PID information	(pre) PID information (post) P > 0.01, rank 10		
	Gamma	deposited energy, shape information from calorimeters, PID information	(pre) deposited energy (post) P > 0.01, rank 20		
Intermediate state particles	$\pi^{0}, K_{S}^{0}, J/\psi, D^{0}, D^{+}, D_{S}^{+}, D^{0*}, D^{+*}, D_{S}^{+*}$	kinematic variables, vertex variables, $\prod P_{daughter}$	(pre) $\prod P_{daughter}$ , $\triangle M$ (pre) released energy ( $D^*$ ) (post) P > 0.001, rank > 10		
B meson	B <sub>hadronic</sub> , B <sub>semileptonic</sub>	kinematic variables, vertex variables, $\prod P_{daughter}$ (excluding invariant mass or angular variables)	(pre) ∏ <i>P<sub>daughter</sub></i> (post) P rank 20		

#### Data Flow Overview (Belle II)



#### Steps for Simulation

Steps for simulation of detector-based B meson analysis

- Decay mode information is used to randomly generate tables(.gen) with event generation toolkit(EvtGen[4]).
- From the generation table, detector simulation with GEANT3[5] (or Geant4[6])
   calculates the interaction between particles and variables.
- Simulation result(.mdst) is constructed from detector simulation.
  - Particles will be reconstructed from simulation results.





### Introduction of $B^0 \rightarrow \ell^{\pm} \tau^{\mp}$ Decay

Lepton flavor violation in  $B^0 \rightarrow \ell^{\pm} \tau^{\mp}$ 

- Forbidden in the Standard Model
- Predicted to occur in 'beyond the Standard Model' theories

Research for  $B^0 \rightarrow \ell^{\pm} \tau^{\mp}$ 

- BaBar collaboration (2008)[4]
  - $\,\circ\,$  Using hadronic tagging method with  $378\times 10^6\,B\bar{B}$  pairs
  - $\Gamma(B^0 \rightarrow e^{\pm} \tau^{\mp}) < 2.8 \times 10^{-5}$
  - $\Gamma(B^0 \to \mu^{\pm} \tau^{\mp}) < 2.2 \times 10^{-5}$
- Belle collaboration (by Hulya Atmacan, 2021)[5]
  - $\,\circ\,$  Using hadronic tagging method(FR) with 771  $\times\,10^6\,B\bar{B}$  pairs
  - $\Gamma(B^0 \to e^{\pm} \tau^{\mp}) < 1.6 \times 10^{-5}$
  - $\Gamma(B^0 \to \mu^{\pm} \tau^{\mp}) < 1.5 \times 10^{-5}$
- My research
  - $\,\circ\,$  using semileptonic tagging method(FEI) with 771  $\times\,10^6\,B\bar{B}$  pairs, ongoing

	$B^0$	$\rightarrow$	e-	$\tau^+$
e lepton number	0	¥	1	0
au lepton number	0	≠	0	-1
	$B^0$	$\rightarrow$	$\mu^{-}$	$\tau^+$
$\mu$ lepton number	0	≠	1	0
au lepton number	0	¥	0	-1



Feynman diagram of  $B^0 \rightarrow e^+ \tau^-$  with neutrino oscillation