Search for Lepton Flavor Violating $B^+ \to K^+ \tau^\pm \ell^\mp$ Decays at Belle

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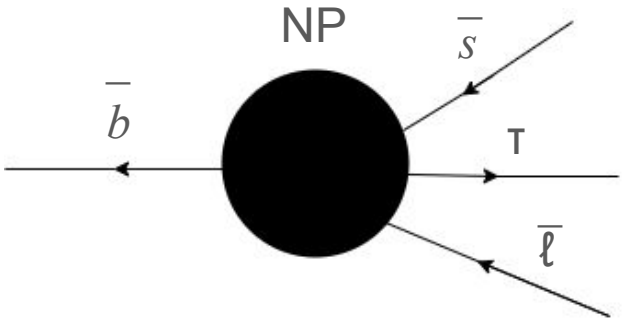
Motivation

- Lepton Flavor is an accidental symmetry in the Standard Model (SM) Lagrangian.

- In the SM, $B \rightarrow K\tau\ell$, ($\ell = e,\mu$) decays are not allowed because of the lepton flavor violation.

- Third generational coupling and τ presence are sensitive to new physics (NP). Some NP models predict BR in the range of 10^{-5}-10^{-7}(1).



Current upper limits (1)

$B(B^+ \rightarrow K^+\tau^+\mu^-) < 0.59\times10^{-5}$
$B(B^+ \rightarrow K^+\tau^+e^-) < 1.51\times10^{-5}$
$B(B^+ \rightarrow K^+\tau^-\mu^+) < 2.45\times10^{-5}$
$B(B^+ \rightarrow K^+\tau^-e^+) < 1.53\times10^{-5}$

1. S. Watanuki et al., PhysRevLett.130.261802

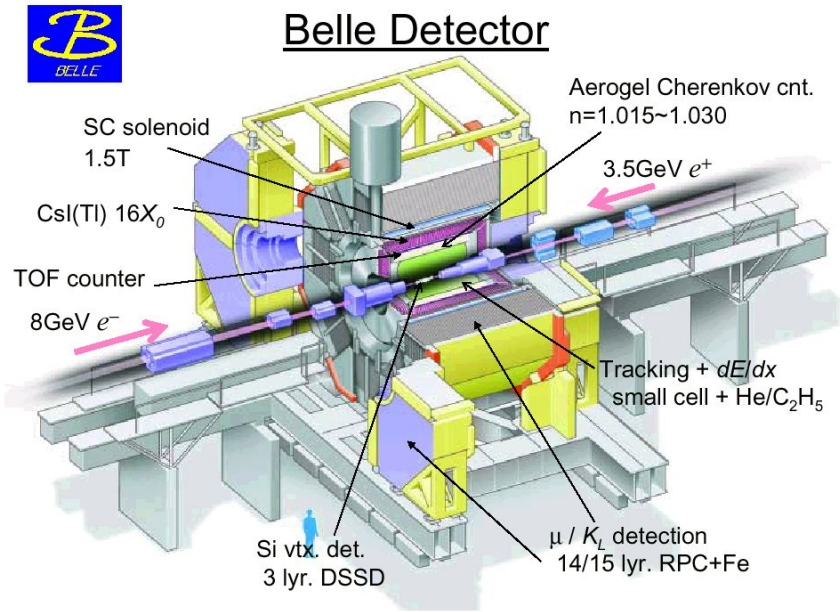
Experimental setup

- Based on an asymmetric leptons collider where most of the data was collected at Y*(4S)*.

$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$$

- One *B* is named as signal *B* (B_{sig}) and the other as tag *B* (B_{tag}).

- It operated from 1999-2010 and has collected 1 ab^{-1} data.



Analysis approach

- Complete decay has the following form:

$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B^+B^-$$

$$(B_{sig}) \qquad B^+ \rightarrow K^+\tau^-\mu^+$$

$$\tau^- \rightarrow \pi^-\nu_\tau \qquad \text{(missing neutrino)}$$

$$(B_{tag}) \qquad B^- \rightarrow X\ell^-\nu_\ell \qquad \text{(semileptonic tag)}$$

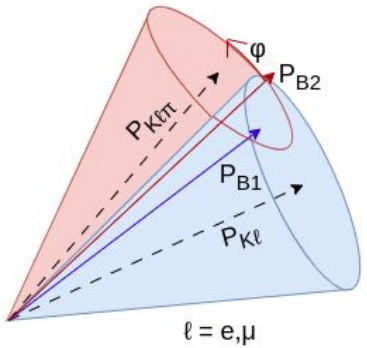
- First we assume τ is missing so the p_{Bsig} can be constrained on the cone around $p_{K\mu}$, then we consider the $\tau \rightarrow \pi\nu_\tau$ decay and constrain the p_{Bsig} on the cone around $p_{K\pi\mu}$ (missing neutrino).
- Intersection of these two cones, provide us the p_{Bsig} momentum with two fold ambiguity (p_{B1},p_{B2}).

Note: In this presentation only $B^+ \rightarrow K^+\tau^-\mu^+$ mode is discussed and same method will be used for other three decay modes.

$B^+ \rightarrow K^+\tau^+\mu^-$

$B^+ \rightarrow K^+\tau^+ e^-$

$B^+ \rightarrow K^+\tau^- e^+$



Tag side reconstruction

- Complete decay is following

$$B^+ \rightarrow K^+ \tau^- \mu^+$$

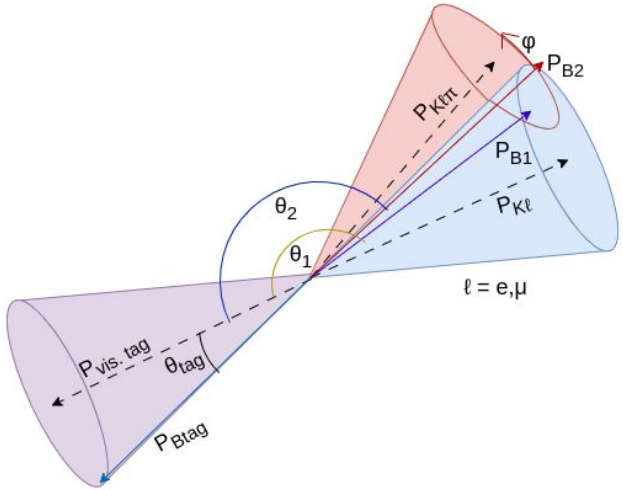
$$\tau^- \rightarrow \pi^- \nu_\tau$$

$$B^- \rightarrow X \ell^- \nu_\ell$$

- Based on this reconstruction, a variable $\Delta\cos\theta$ is defined as

$$\Delta\cos\theta = \min |\cos\theta_{[1,2]} + \cos\theta_{tag}|$$

- It contains information from both signal and tag side.



Hadronic tagging is also used with the encouraging results (2).

2. M. Kaleta, M.S thesis, Belle Collaboration.

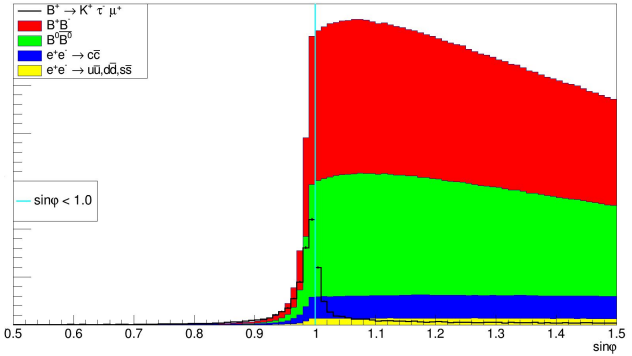
Preliminary selections

- To reduce the background, we will make some preliminary selections.
- **sinφ < 1.0** rejects majority background on the signal side.
- Semi-leptonic *B* & *D* decays can mimic our signal so to reject them we use $\mathbf{m_{K\pi}}$**>1.91 GeV**.
- After some more preliminary selections.

$\boldsymbol{\varepsilon_{sig} = 3.9\times10^{-3}}$, $\boldsymbol{\varepsilon_{bg} = 1.0\times10^{-6}}$

Sample size:
1.0 M Dedicated $B^+\to K^+\tau^-\,(\to\pi^-\nu_\tau)\mu^+$ MC.
3.0xBelle data (norm. to Belle data) for generic MC.

a.u



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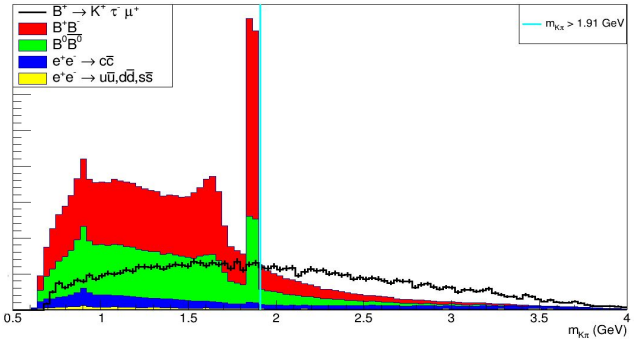


Boosted Decision Trees (BDT) approach

- **Signal sample:** Training (70%) and testing (30%) is done on the dedicated 1.0 M, $B \rightarrow K\tau(\rightarrow \pi\nu_\tau)\mu$ sample.

- **Background sample:** 10×Belle data (7×training, 3×testing) of generic MC is used for B^+B^- and $B^0\,\overline{B}^0$.

- **Application sample:** Application of BDT is performed on the dedicated 8.9 M, $B \rightarrow K\tau(\rightarrow \text{all})\mu$ sample and 1×Belle data for background.

- N_{sig} and N_{bg} are estimated for Belle luminosity.

BDT optimization

- To optimize the BDT score cut, Punzi figure of merit is used which is defined as

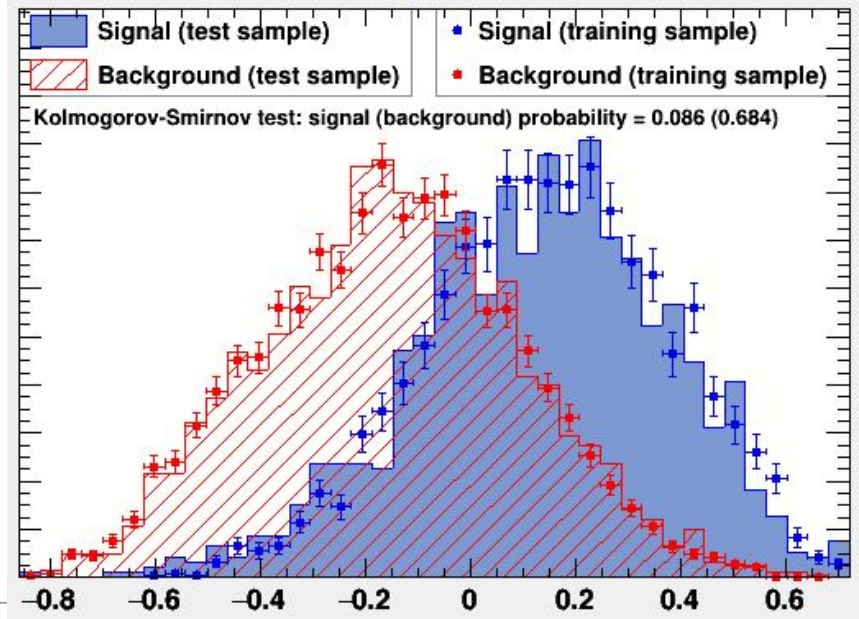
$$FOM_{Punzi} = \frac{\epsilon(t)}{\frac{\alpha}{2} + \sqrt{B(t)}}$$

Where

$\varepsilon(t)$ = signal efficiency

α = desired significance

$B(t)$ = remaining background events

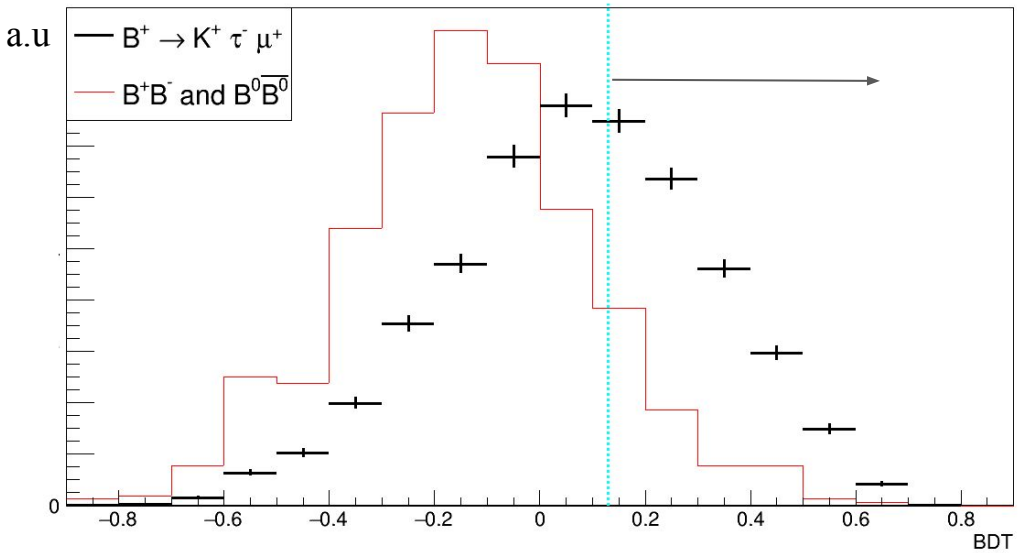


BDT > 0.13 (optimal cut) , α=3

#Signal	#Backg.	Cut	PFOM	Signal retention eff.	Bkg. rejection eff.
1186	803	0.13	1.7×10^{-4}	53%	86%

Final BDT score

- For BDT> 0.13 and corresponding to BF of 5×10^{-5}.

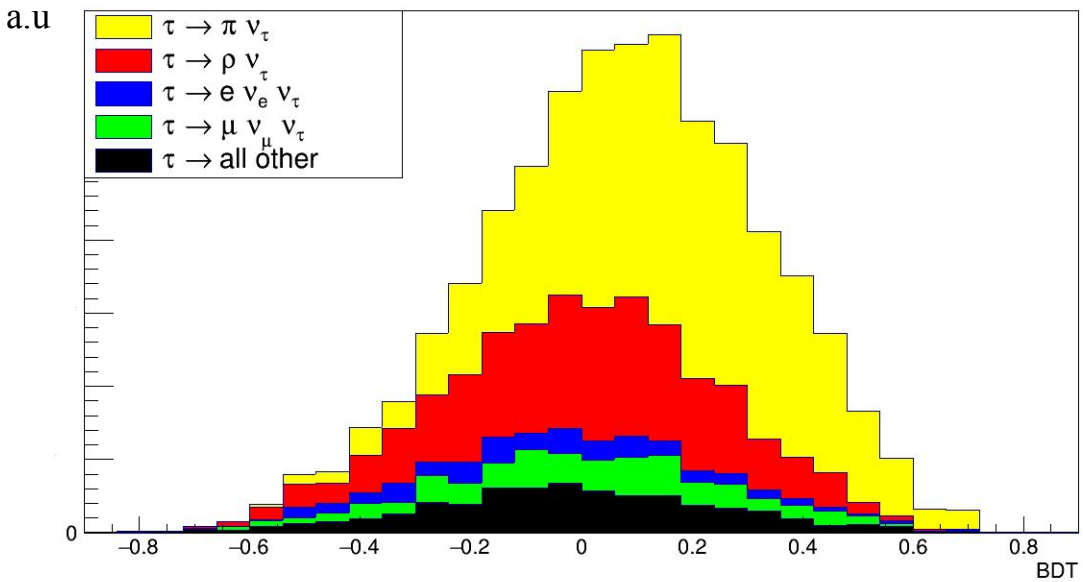


N_{sig} = 13 (**9** for $\tau\to\pi\nu_\tau$ mode)
N_{bg} = 102

Cross feeds

- We expect some cross feeds from different τ decays.
- Max. cross feed is from the $\tau \rightarrow \rho\nu_\tau$ channel.

τ daughters	Percentage
$\pi\nu_\tau$	66%
$e\nu_e\nu_\tau$	3%
$\mu\nu_\mu\nu_\tau$	6%
$\rho\nu_\tau$	19%
others	6%



Control modes validation

- We are using the following decays as our control channel modes.

$B^+ \rightarrow J/\psi\, K^+$ (BF = 1.02×10^{-3}) , $B^+ \rightarrow \bar{D}^0\, \pi^+$ (BF = 4.61×10^{-3})

$J/\psi \rightarrow \mu^+\mu^-$ (BF = 5.9×10^{-2}) $\bar{D}^0 \rightarrow K^+\pi^-$ (BF = 3.9×10^{-2})

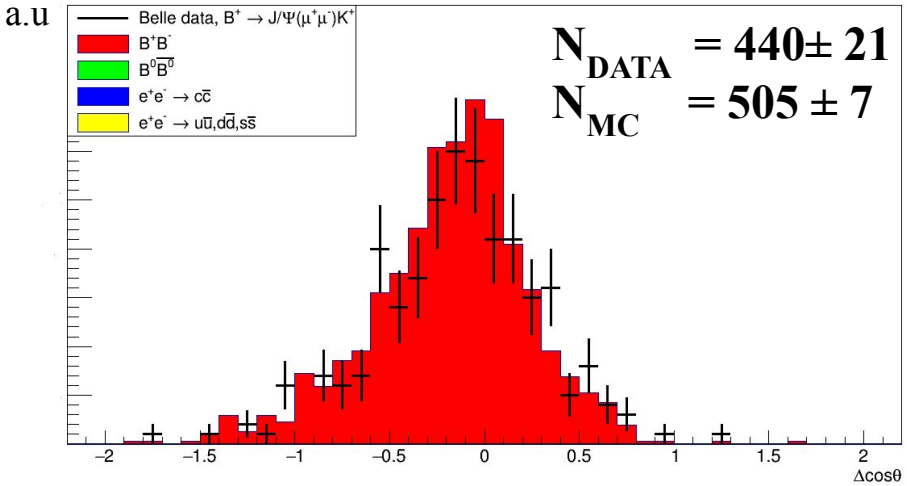
- Topology of these decays are similar to our signal decay.

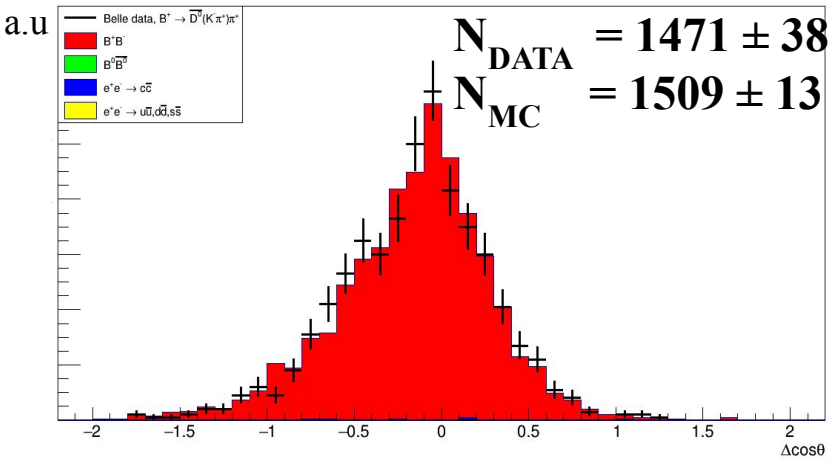
- We assume that one particle (μ,π) is missing, so that they can replicate our signal decay reconstruction.

Sample size:
Complete Belle data.
3.0xBelle data (norm. to Belle data) for generic MC.

Δcosθ for control modes

- After our all selections on the control modes, we have the distributions of Δcosθ.
- Reasonable agreement of shape between data and MC.





Summary and outlook

- We have developed new tools for studying the $B \to K\tau\ell$ decays (with sensitivity ~ 10^{-4}) using a unique new inclusive semileptonic tagging approach in Belle.

- We have validated the results using the two different control channel modes.

- To increase our sensitivity we will include other τ decay modes.

- We will extract the signal by using the template fitting on the final BDT score.

Backup

Input variables

Input variables = {Δcosθ, ΔE_{Btag}, p_{ltag}, m_{ROE}, $n_{photons}$, n_{Lepton}}

Δcosθ is providing the best discrimination.