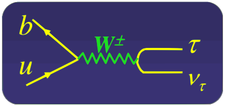
$B \to \tau\nu$ and $B \to D^{(*)}\tau\nu$ at Belle

Outline

1. Motivation
2. Belle apparatus
3. Multineutrino B decays – experimental techniques
4. Results
5. Summary and outlook

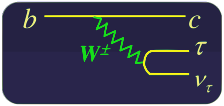
Motivation

tauonic and semitauonic B decays



$B \to \tau\nu_\tau$

- B decay constant f_B

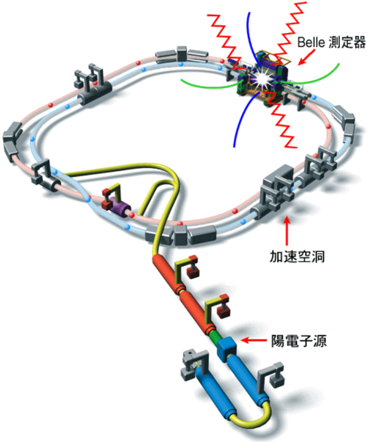


$B \to D^{(*)}\tau\nu_\tau$

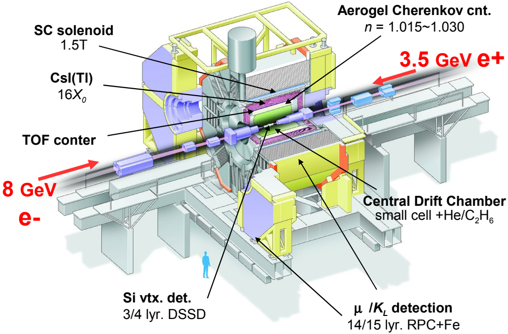
- form-factors that cannot be accessed in other semileptonic B decays

- sensitive to extended Higgs sector – new physics at tree level
- large branching fracton effects
- sensitive observables *e.g.* τ polarization – possible $\mathcal{O}(1)$ effects
- Hbu and Hbc vertices complementary to Htb searches at the LHC

- poorly known – experimentally difficult
- not observed exclusively before B-factories



Belle detector: multi-purpose, large-solid-angle magnetic spectrometer

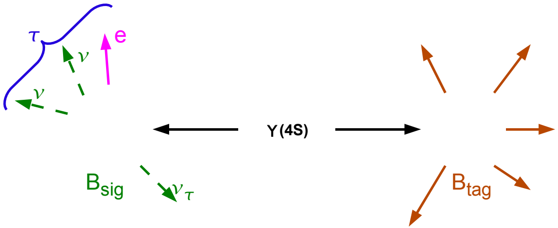


characteristics

$e^+e^- \to \Upsilon(4S) \to B\overline{B}$ clean source of exclusive B meson pairs

$\mathcal{L}_{\text{peak}} = 2.11 \times 10^{34}$ $\int \mathcal{L} > 1\ \text{ab}^{-1}$ $711\ \text{fb}^{-1}$ @ $\Upsilon(4S)$

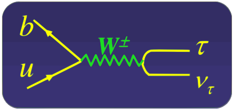
Signal decay with multiple (2 or 3) neutrinos can be observed using kinematic constraints available only at B-factories. To ensure that we have missing 4-momentum consistent with multineutrino hypothesis we take the advantage of exclusive $B\overline{B}$ production.



two ways of $B_{\rm tag}$ reconstruction

1. reconstruct $B_{\rm tag}$ (in exclusive mode) and check whether remaining particles are consistent with $B_{\rm sig}$ ("exclusive" $B_{\rm tag}$ reconstruction)
2. select $B_{\rm sig}$ candidate and check whether remaining particles are consistent with B decay ("inclusive" $B_{\rm tag}$ reconstruction)

$B \to \tau \nu_\tau$



SM: W-mediated annihilation

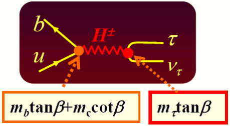
decay rate simply related to B decay constant f_B and $|V_{ub}|$:

$$\mathcal{B}(B \to l\nu)\Big|_{\mathrm{SM}} = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

most accessible purely leptonic B decay[1]

$$\mathcal{B}(B \to l\nu)\Big|_{\mathrm{SM}} = (1.2 \pm 0.25) \times 10^{-4}$$

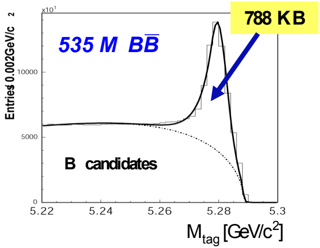
$$|V_{ub}| = (4.32 \pm 0.16 \pm 0.29) \times 10^{-3}$$
$$f_B = 190 \pm 13\mathrm{MeV}$$



sensitive to charged Higgs from type-II 2HDM[2]

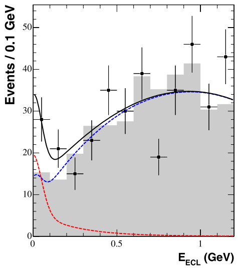
$$\mathcal{B} = \mathcal{B}\Big|_{\mathrm{SM}} \times r_H \qquad r_H = \left(1 - \frac{m_B^2}{m_H^2} \tan^2\beta\right)^2$$

[1] $|V_{ub}|$ taken from HFAG ICHEP08, f_B taken from HPQCD arXiv:0902.1815v3 [hep-lat]
[2] W. S. Hou, PRD **48**, 2342 (1993)



$$M_{\rm tag} = \sqrt{E_{\rm beam}^2 - \left(\sum_{i \notin {\rm sig}} \vec{p}_i\right)^2}$$

$$\Delta E_{\rm tag} = \sum_{i \notin {\rm sig}} E_i - E_{\rm beam},$$



← hadronic tag 449M $B\overline{B}$[3]

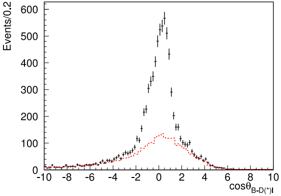
First evidence 3.5σ

$$\mathcal{B}(B \to \tau\nu) = [1.79^{+0.56}_{-0.49}({\rm stat})^{+0.46}_{-0.51}({\rm syst})] \times 10^{-4}$$

E_{ECL} – residual energy in calorimeter

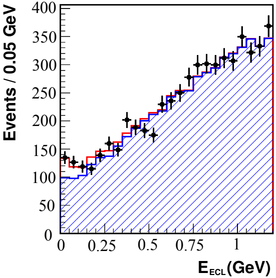
[3] PRL **97**, 251802 (2006)

$B^+ \to \tau^+\nu_\tau$ results with exclusive semileptonic B_{tag} reconstruction



$$\cos\Theta_{B,D^{(*)}l} = \frac{2E^{cms}_{beam}E^{cms}_{D^{(*)}l} - m_B^2 - M^2_{D^{(*)}l}}{2P^{cms}_B \cdot P^{cms}_{D^{(*)}l}}$$

$$P^{cms}_B = \sqrt{(E^{cms}_{beam})^2 - m_B^2}$$



← semileptonic tag 657M $B\overline{B}$ NEW![4]

3.6σ

$$\mathcal{B}(B \to \tau\nu) = [1.54^{+0.38}_{-0.37}(\text{stat})^{+0.29}_{-0.31}(\text{syst})] \times 10^{-4}$$

Standard Model predictions

SM+LQCD: $\mathcal{B}(B \to \tau\nu)_{\text{SM}} = [1.2 \pm 0.25] \times 10^{-4}$

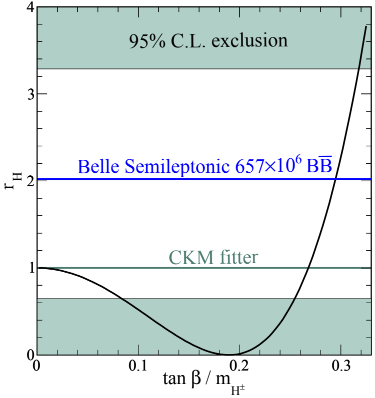
CKM fitter[5]: $\mathcal{B}(B \to \tau\nu)_{\text{CKM}} = [0.763^{+0.113}_{-0.061}] \times 10^{-4}$

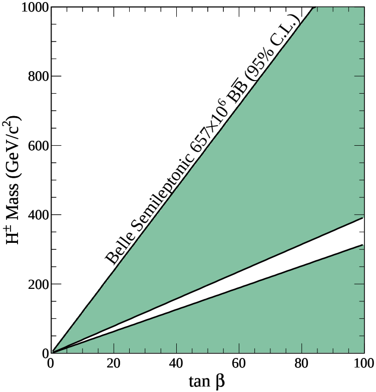
[4] arXiv:1006.4201v1 [hep-ex] submitted to PRD

[5] `http://ckmfitter.in2p3.fr/plots_FPCP10/`

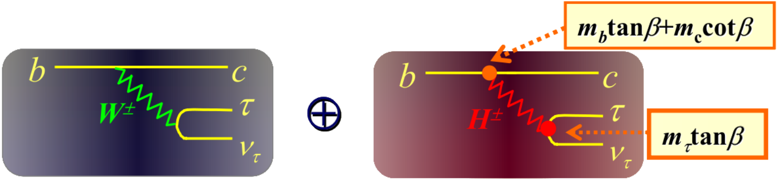
effects of charged Higgs from type-II 2HDM on BF

$$\mathcal{B}(B^+ \to \tau^+\nu_\tau) = \mathcal{B}(B^+ \to \tau^+\nu_\tau)\big|_{\mathrm{SM}} \times r_H \qquad r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$





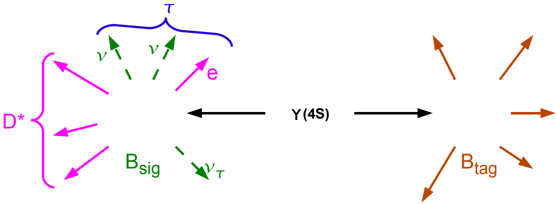
$B \to \overline{D}^{(*)}\tau^+\nu_\tau$



- sensitive to extended Higgs sector; complementary to and competitive with $B \to \tau\nu$
- different theory uncertainties:
  - free from f_B and $|V_{ub}|$, depends on the $B \to \overline{D}^{(*)}\tau^+\nu_\tau$ formfactors
  - $|V_{cb}|$ (known better than $|V_{ub}|$) cancels out in the ratio $\frac{\mathcal{B}(B\to D\tau\nu)}{\mathcal{B}(B\to Dl\nu)}$
- 3-body decay $\Rightarrow$ more observables (*e.g.* q^2-distribution, τ polarization, D^* polarization)

- B_{sig} clean signature *e.g.* $D^{*-}e^+$
- reconstruct B_{tag} inclusively

B_{sig} decay chains that combine a high reconstruction efficiency with a low background level were chosen



$$D^* \to \overline{D}^0\pi$$

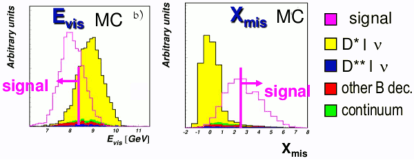
$$\overline{D}^0 \to K^+\pi^-, \qquad \overline{D}^0 \to K^+\pi^-\pi^0$$

$$\tau \to \pi\nu, \quad \tau \to l\nu\nu, \quad l = e, \mu$$

background suppression

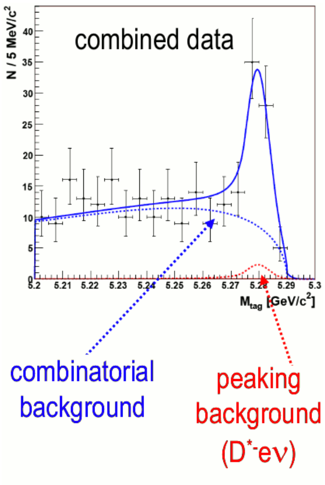
- visible energy E_{vis}
- $X_{\text{mis}} = \frac{E^2_{\text{mis}} - |\vec{p}_{D^*} + \vec{p}_{l/\pi}|}{|\vec{p}_B|}$

similar to M_{mis} but M_{tag} independent



FIRST OBSERVATION[6]

$\mathcal{B}(B^0 \to D^{*-}\tau^+\nu_\tau) = (2.02^{+0.40}_{-0.37}(\text{stat}) \pm 0.37(\text{syst}))\%$



signal yield in 535M $B\overline{B}$

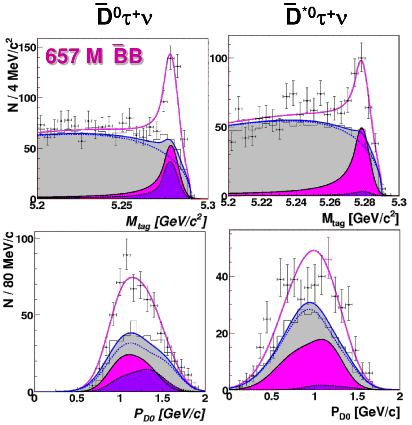
$N_S = 60^{+12}_{-11}$ 6.7σ (5.2σ with syst.)

from a combined maximum likelihood fit (with a single BF) to M_{tag} distributions for all sub-decay modes

At large X_{mis} most of background components behave combinatorial while the signal is visible as a well reconstructed B_{tag}.

[6]PRL **99**, 191807 (2007)

- simultaneous extraction of signals in $B^+ \to \overline{D}^{*0}\tau^+\nu_\tau$ and $B^+ \to \overline{D}^0\tau^+\nu_\tau$ taking into account $\overline{D}^{*0} \leftrightarrow \overline{D}^0$ cross-feeds
- signal extraction from fit to 2-dim distributions in $M_{\rm tag}$ and P_{D^0} (momentum of D^0 in $\Upsilon(4S)$ rest frame)
- simultaneous fit to 13 decay chains with floating 2 signal BFs and 13 background normalizations



$N(\overline{D}^{*0}\tau^+\nu_\tau) = 446^{+58}_{-56}$ **8.1σ**

$BF(B^+ \to \overline{D}^{*0}\tau^+\nu_\tau) = (\mathbf{2.12}^{+0.28}_{-0.27} \pm 0.29)\times 10^{-2}$

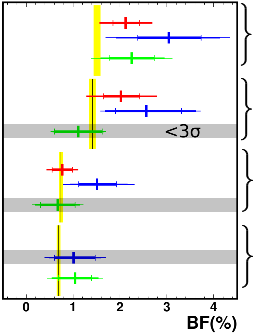
$N(\overline{D}^{0}\tau^+\nu_\tau) = 146^{+42}_{-41}$ **3.5σ** **first evidence**

$BF(B^+ \to \overline{D}^{0}\tau^+\nu_\tau) = (\mathbf{0.77}^{+0.22}_{-0.22} \pm 0.12)\times 10^{-2}$

signal combined
$\overline{D}^{*0}\tau^+\nu$
$\overline{D}^{0}\tau^+\nu$
background

arXiv:1005.2302
submitted to PRL

there are preliminary Belle results with exclusive B_{tag} reconstruction using 657M $\overline{B}B$[7]



$B^+ \to \overline{D}^{*0}\tau^+\nu_\tau$ $[2.12^{+0.28}_{-0.27} \pm 0.29]\%$ 8.1σ
$[3.04^{+0.69}_{-0.66}{}^{+0.40}_{-0.47}]\%$ 3.9σ

$B^0 \to D^{*-}\tau^+\nu_\tau$ $[2.02^{+0.40}_{-0.37} \pm 0.37]\%$ 5.2σ
$[2.56^{+0.75}_{-0.66}{}^{+0.31}_{-0.22}]\%$ 4.7σ

$B^+ \to \overline{D}^{0}\tau^+\nu_\tau$ $[0.77 \pm 0.22 \pm 0.12]\%$ 3.5σ
$[1.51^{+0.41}_{-0.39}{}^{+0.24}_{-0.19}]\%$ 3.8σ

$B^0 \to D^{-}\tau^+\nu_\tau$ $[1.01^{+0.46}_{-0.41}{}^{+0.13}_{-0.11}]\%$ 2.6σ

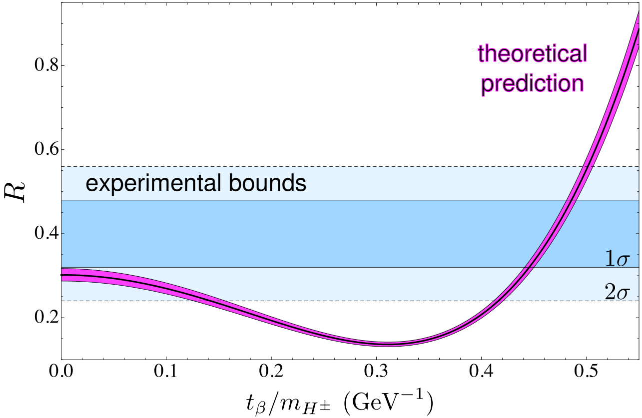
– Belle inclusive B_{tag}
– Belle exclusive B_{tag}
– BaBar exclusive B_{tag}[8]
Standard Model[9]

- similarly to $B \to \tau\nu$ results are above SM predictions
- inclusive reconstruction gives the smalest statistical errors

[7] arXiv:0910.4301v1 [hep-ex]
[8] PRL **100**, 021801 (2008)
[9] C.-H. Chen and C.-Q. Geng, JHEP **0610**, 053 (2006)

$B \to \overline{D}\tau^+\nu_\tau$ constraints on theoretical models

experimental bounds on $\tan\beta/m_H$ in type-II 2HDM from averaged Belle and BaBar measurements[10] of $R = \frac{\mathcal{B}(B\to D\tau\nu_\tau)}{\mathcal{B}(B\to Dl\nu_l)} = 0.40 \pm 0.08$



[10] M. Tanaka, R. Watanabe, arXiv:1005.4306

Summary and outlook

- B-factory is a good environment for studies of tauonic and semitauonic B decays
- new measurement by Belle of $B \to \tau\nu_\tau$ with semileptonic tags
  BF $= [1.54^{+0.38}_{-0.37}(\text{stat})^{+0.29}_{-0.31}(\text{syst})] \times 10^{-4} (3.6\sigma)$
- measurements of (semi)tauonic-B decays are now well established and provide constraints on charged Higgs sector that are competitive with direct searches
- measured BFs are consistent within experimental uncertainties with expectations of the SM, but there is still some room for new physics
- full data set analysis is on the way
- interesting prospects for Super B-factories (Belle II at SuperKEKB)

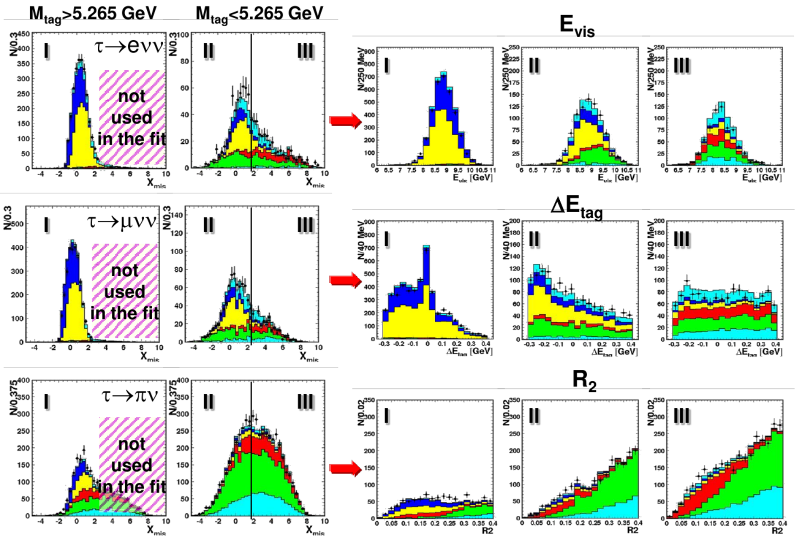
BACKUP

Background calibration

Search for $B^+ \to \bar{D}^{(*)0}\tau^+\nu_\tau$

- $B \to \bar{D}^{**} l^+\nu_l$
- $B \to \bar{D}\, l^+\nu_l$
- $B \to \bar{D}^{*} l^+\nu_l$
- other B dec.
- cc-bar cont,
- uds-cont.

$B^+ \to \bar{D}^0\tau^+\nu_\tau$



scale factors

$B \to \bar{D}^{**} l^+\nu_l$	0.53
$B \to \bar{D}\, l^+\nu_l$	0.90
$B \to \bar{D}^{*} l^+\nu_l$	0.80
other B dec.	1.04
cc-bar cont,	1.07
uds-cont.	1.05

$B \to \bar{D}^{**} l^+\nu_l$	0.53
$B \to \bar{D}\, l^+\nu_l$	0.90
$B \to \bar{D}^{*} l^+\nu_l$	0.80
other B dec.	1.04
cc-bar cont,	1.07
uds-cont.	1.05

$B \to \bar{D}^{**} l^+\nu_l$	0.53
$B \to \bar{D}\, l^+\nu_l$	0.90
$B \to \bar{D}^{*} l^+\nu_l$	0.80
other B dec.	0.99
cc-bar cont,	2.02
uds-cont.	0.58

B→D$^{(*)}$τν Semileptonic TagSystematic Errors of Yield

B_{tag}-reconstruction	±12.9	±12.8
BG shape	±3.3	±2.7
signal PDF shape	±2.5	±6.0
Signal selection	+1.3/−1.4	+4.2/−4.4
Total	+13.9	−15.2

method $B^+ \to \tau^+ \nu_\tau$

reconstruct B_{tag} in exclusive modes

- **full reconstruction in a hadronic mode**

$$B^- \to D^{(*)0}\pi^- / \rho^- / a_1^- / D_s^{(*)-}$$

$$\boxed{M_{bc} = \sqrt{E_{beam}^2 - (\sum \vec{p}_i)^2}, \quad \Delta E = \sum E_i - E_{beam}}$$

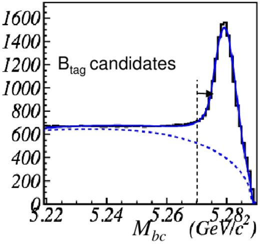
efficiency~0.2%

- **partial reconstruction in a semileptonic mode**

$$B^- \to D^{(*)0} l^- \nu_l, \;\; l = e, \mu$$

$$\boxed{\cos\theta_{(B^-, D^{(*)}l)} = \frac{2E_{beam}E_{D^{(*)}l} - M_B^2 - M_{D^{(*)}l}^2}{2P_B P_{D^{(*)}l}}}$$

efficiency ~0.7%;
larger background
complementary sample

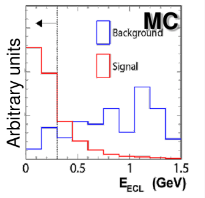


signal side: $\tau^+ \to e^+\nu\nu,\ \mu^+\nu\nu,\ \pi^+\nu,\ \rho^+\nu,\ (3\pi)^+\nu$

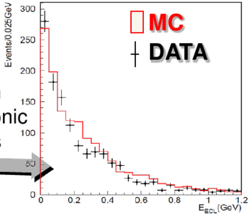
signal signature: no particle left after removing B_{tag} and B_{sig} daughters

E_{ECL}: residual energy in calorimeter

for signal $E_{ECL} \approx 0$



validation with double semileptonic tagged events



$B \to \tau\nu$ Semileptonic TagSystematic Errors of Yield

BG PDF shape	+18.1	−17.2
Signal PDF shape	+3.1	−3.2
Br of peaking BG	+6.4	−13.0
Rare B, $b \to u l \nu$, τ pair BG	+5.9	−5.9
Efficiency ratio	+0.5	−0.6
Total	+20.3	−22.3

19