B decays to τ leptons at Belle
$B \rightarrow \tau\nu$ / $D\tau\nu$

Toru Iijima

Nagoya University

September 15, 2010

Tau 2010 @ Manchester

Take Outline

- Introduction
- Purely leptonic decay $B \rightarrow \tau\ \nu$
- Semileptonic decay $B \rightarrow D^{(*)}\ \tau\ \nu$
- Prospects
- Summary

τ as a probe to New Physics in B decays.

Charged Higgs in b→τ

- Extensions of the SM, which require >2 Higgs doublets, generate new flavor-changing interactions at tree-level via exchange of a charged Higgs.
- The H^+ coupling is proportional to the fermion mass, and it is natural to look at (semi-)leptonic B decays into a τ in the final state.

B→τ transition (MSSM)

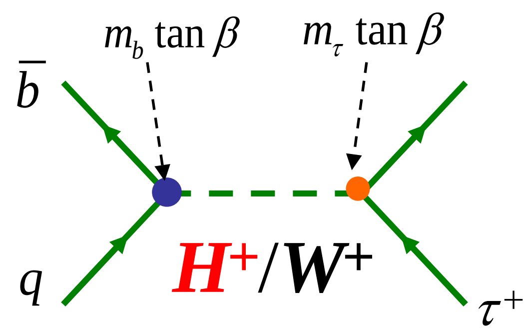
$$\mathcal{H}^{\text{eff}} = 2\sqrt{2}\,G_F\,V_{qb}\{(\bar{b}_L\,\gamma^\mu\,q_L)\,(\bar{\nu}_L\,\gamma_\mu\,\tau_L) - \frac{m_b m_\tau}{m_B^2} g_S\,(\bar{b}_R\,q_L)\,(\bar{\nu}_L\,\tau_R)\};$$

Effective scalar coupling;

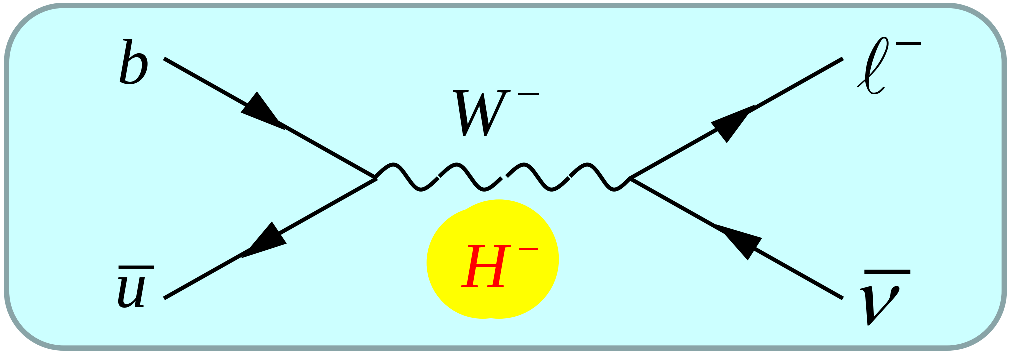
$$g_S = \frac{M_B^2 \tan^2\beta}{M_H^2} \frac{1}{(1+\varepsilon_0\tan\beta)(1+\varepsilon_\tau\tan\beta)},$$

SUSY Loop correction

$\varepsilon_0=\varepsilon_\tau=0$ in Type-II 2HDM



$B^- \to \tau^- \bar{\nu}$ (in SM)



※ Helicity suppression

$Br(B \to e\,\nu)$ 10^{-11}

$Br(B \to \mu\,\nu)$ 10^{-7}

$Br(B \to \tau\,\nu)$ 10^{-4}

Within SM, proceed via W annihilation.

$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

From $f_B|V_{ub}|$

$f_B = 190 \pm 13\ MeV$ HPQCD, 0902.1815v2

$|V_{ub}| = (4.32 \pm 0.16 \pm 0.29) \times 10^{-3}$ HFAG ICHEP08

$\Rightarrow$ $Br_{SM}(\tau\nu) = (1.20 \pm 0.25) \times 10^{-4}$

From CKM fit (w/o B→τν in the input)

$\Rightarrow$ $Br_{CKM\ fit}(\tau\nu) = (0.763^{+0.113}_{-0.061}) \times 10^{-4}$ CKM fitter @ ICHEP2010

$Br_{CKM\ fit}(\tau\nu) = (0.805 \pm 0.071) \times 10^{-4}$ UT fit @ ICHEP2010

Charged Higgs Effect in B→τ ν

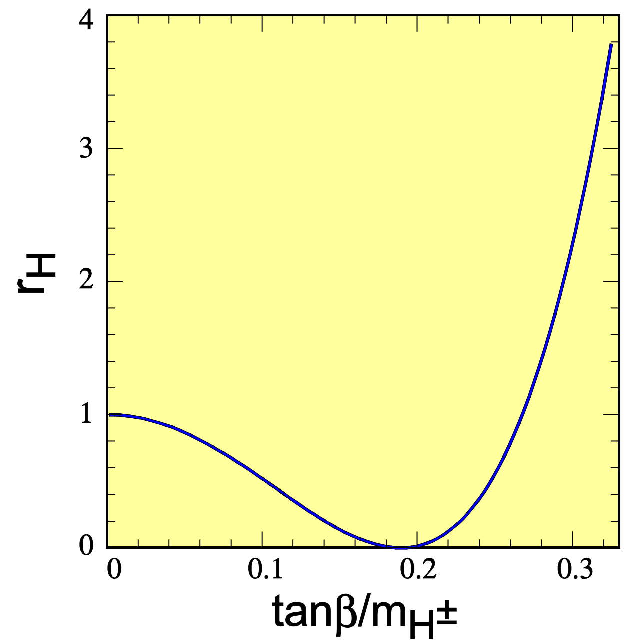
Charged Higgs exchange interferes with the helicity suppressed W-exchange.

⇨ The Br becomes larger or smaller;

$$Br = Br_{SM} \times r_H, \quad r_H = \left|1 - g_s\right|^2$$

Type-II 2HDM

$$Br = Br_{SM} \times r_H, \quad r_H = \left(1 - \frac{m_B^2}{m_H^2} \tan^2\beta\right)^2$$



If $\mu\nu$ is also measured, lepton universality can be tested.

→ SUSY correction etc.

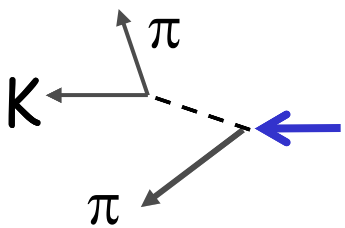
Analysis for $B \to \tau\nu$

S/N

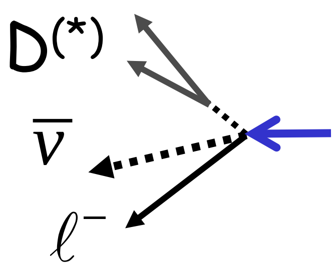
Eff

Tagging side:

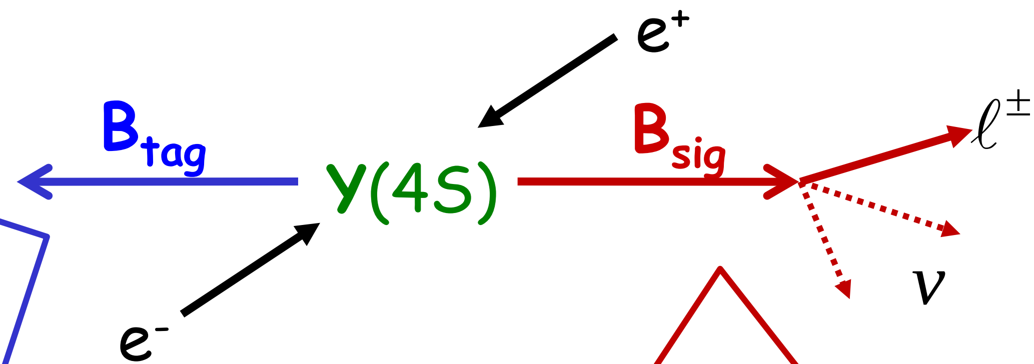
Hadronic tags
$B_{tag} \to D^{(*)}\pi/\rho$ etc.



Semileptonic tags
$B_{tag} \to D^{(*)}l\nu$ etc.

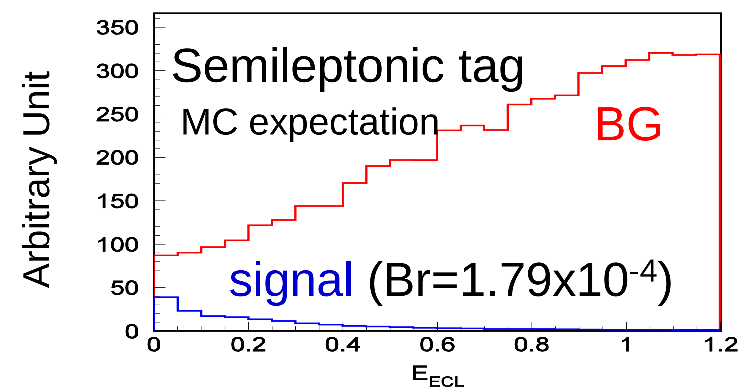


Inclusive tags
Used for Belle $B \to D^{*}\tau\nu$



Signal side: $B_{sig} \to l\,\nu$

- Detect charged track(s)
- Missing energy due to ν's
- No extra activities in EM calorimeter ($E_{ECL(extra)}$)



Belle B→τν w/ Hadronic Tag

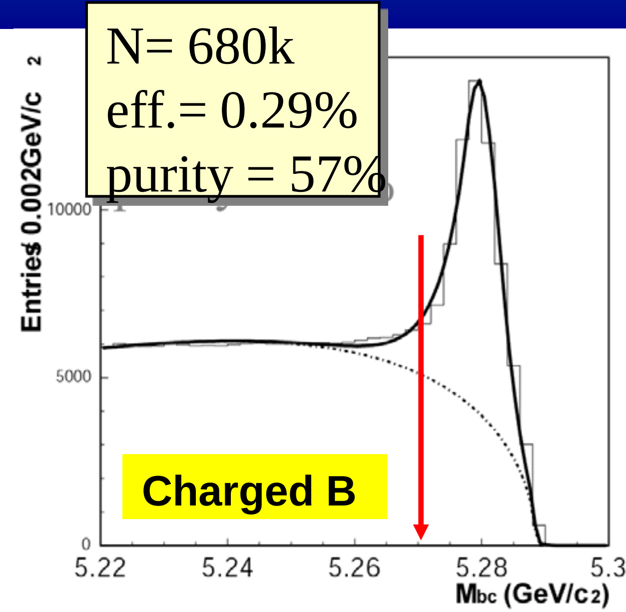
449M $B\bar{B}$ PRL 97, 251802 (2006)

B_{tag} reconstruction;

$$B^+ \to \bar{D}^{(*)0} + \pi^+ / \rho^+ / a_1^+ / D_S^{(*)+}$$
$$\quad \hookrightarrow \bar{D}^0\pi^0 / \bar{D}^0\gamma \qquad \hookrightarrow D_s^+\gamma$$

$$M_{bc} = \sqrt{E_{beam}^2 - (\sum_i \vec{p}_i)^2} \qquad \Delta E = \sum_i E_i - E_{beam}$$

Signal region : -0.08 < ΔE < 0.06 GeV, M_{bc} > 5.27 GeV/c^2



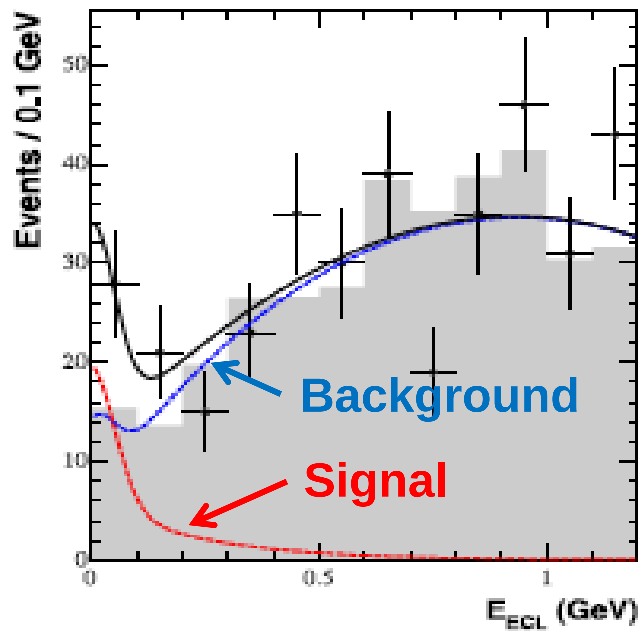
$$Br(\tau\nu) = [1.79^{+0.56}_{-0.49}(stat)^{+0.46}_{-0.51}(syst)] \times 10^{-4}$$

$$N_S = 24.1^{+7.6}_{-6.6}(stat)^{+5.5}_{-6.3}(syst)$$

in all E_{ECL} region.

3.5σ (incl. syst.)

First evidence !



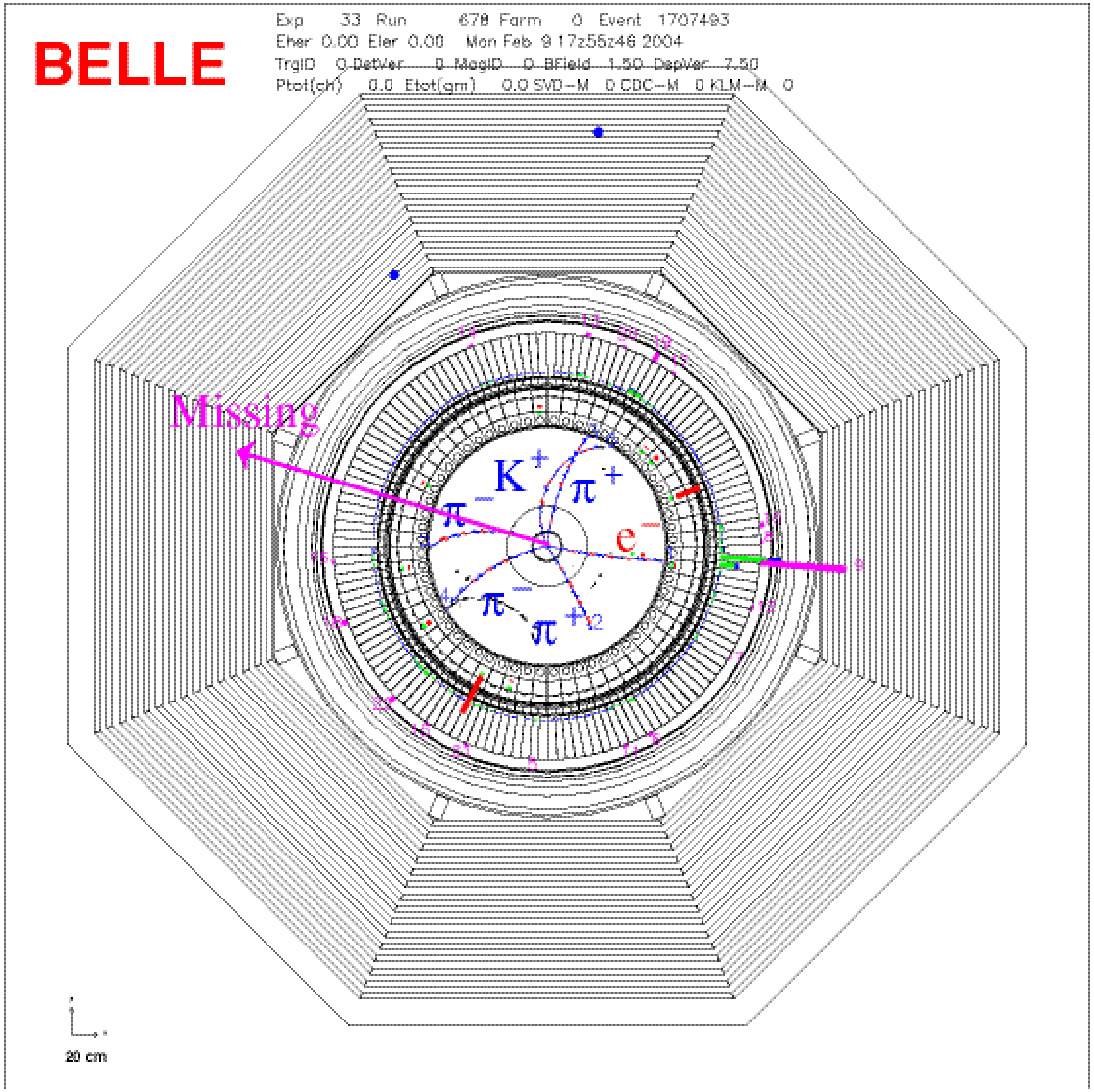
Candidate Event

$B^+ \rightarrow \overline{D}^0 \pi^+$

$\quad \hookrightarrow K^+ \pi^- \pi^+ \pi^-$

$B^- \rightarrow \tau^- \nu$

$\quad \hookrightarrow e^- \nu \nu$



Belle B→τν w/ Semileptonic Tag

- 657M $B\bar{B}$

submitted to PRD-RC, arXiv:1006.4201

B_{tag} reconstruction

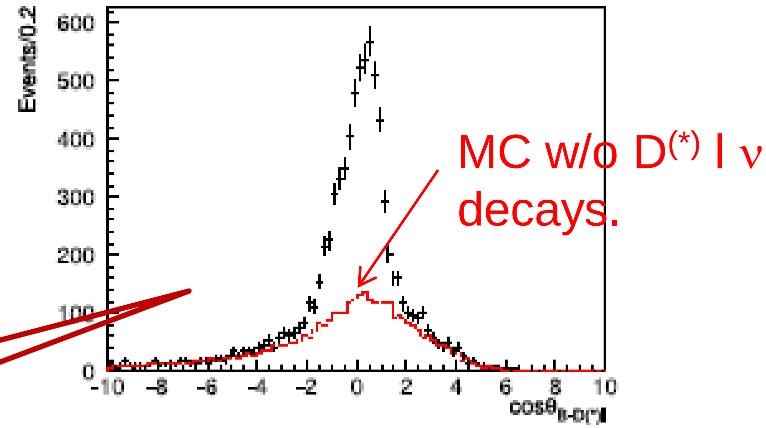
$B^- \to D^{*0} l^+ \nu,\ D^0 l \nu$

$D^{*0} \to D^0 \pi^0,\ D^0 \gamma$

$D^0 \to K^-\pi^+, K^-\pi^+\pi^-\pi^+,\ K^-\pi^+\pi^0$

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

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

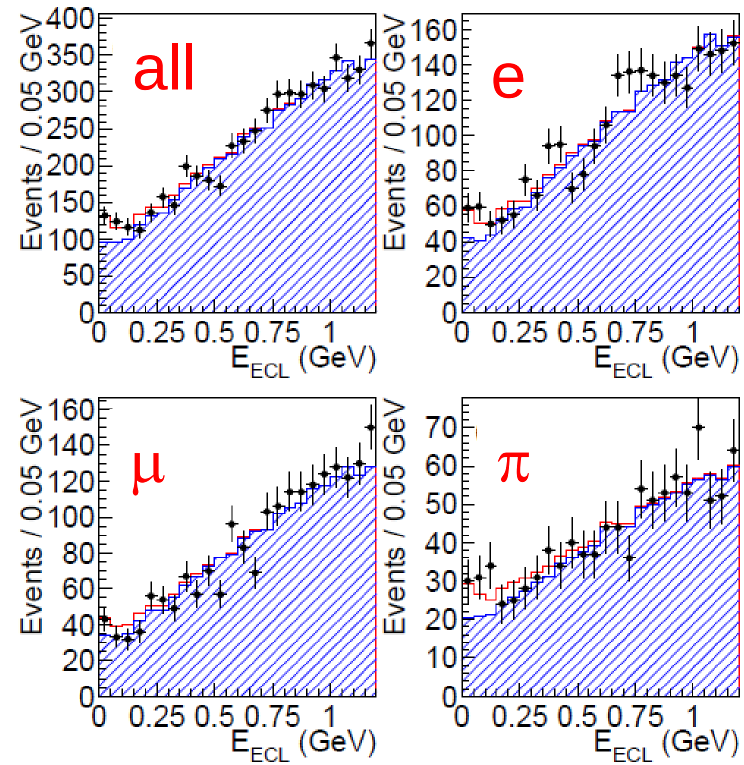


$$Br(\tau\nu) = [1.54\ ^{+0.38}_{-0.37}\ ^{+0.29}_{-0.31}] \times 10^{-4}$$

$$N_S = 143^{+36}_{-35}(\text{stat})$$

3.6σ (incl. syst.)

$$f_B |V_{ub}| = (9.3\ ^{+1.2}_{-1.1} \pm 0.9) \times 10^{-4}\ \text{GeV}$$



Constraint on Charged Higgs

K. Trabelsi @ ICHEP2010

$$Br(\tau\nu) = [1.68 \pm 0.31] \times 10^{-4}$$

$$Br_{SM}(\tau\nu) = [1.20 \pm 0.25] \times 10^{-4}$$

Based on fB from HPQCD and $|V_{ub}|$ from HFAG (BLNP, ICHEP08)

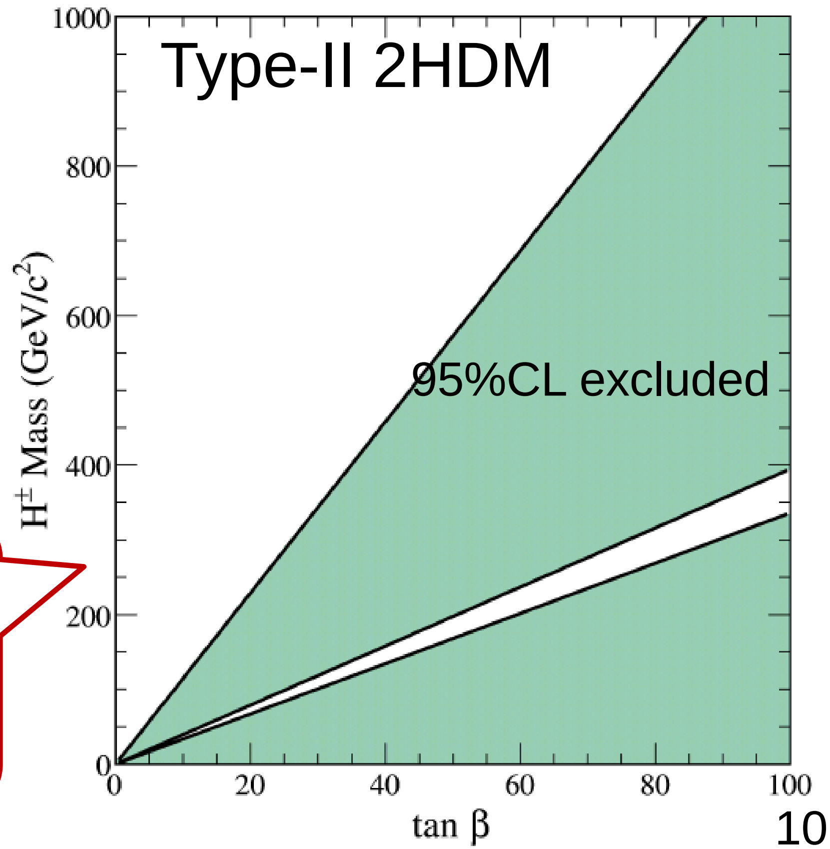
- Belle
  - Hadronic tag (449MBB) :
    $$Br(\tau\nu) = [1.79^{+0.56+0.46}_{-0.49\,-0.51}] \times 10^{-4}$$
  - Semileptonic tag (657MBB):
    $$Br(\tau\nu) = [1.54^{+0.38+0.29}_{-0.37\,-0.31}] \times 10^{-4}$$
- BaBar
  - Hadronic tag:
    $$Br(\tau\nu) = [1.80^{+0.57}_{-0.54} \pm 0.26] \times 10^{-4}$$
  - Semileptonic tag:
    $$Br(\tau\nu) = [1.70 \pm 0.87 \pm 0.20] \times 10^{-4}$$

Effect of Charged Higgs (Type-II 2HDM)

W. Hou, Phys. Rev. D48, 2342 (1993)

$$Br = Br_{SM} \times \left(1 - \frac{m_B^2 \tan\beta^2}{m_H^2}\right)^2$$

Constraint on charged Higgs



Comparison to CKM fit

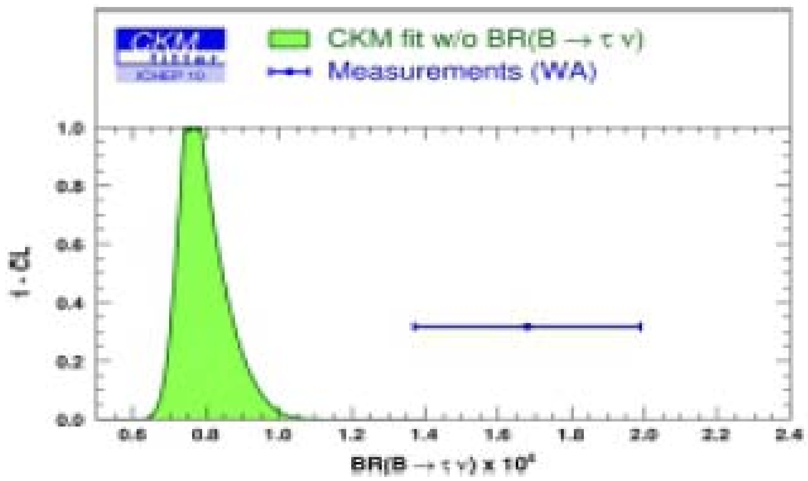
$$Br(\tau\nu) = [1.68 \pm 0.31] \times 10^{-4}$$

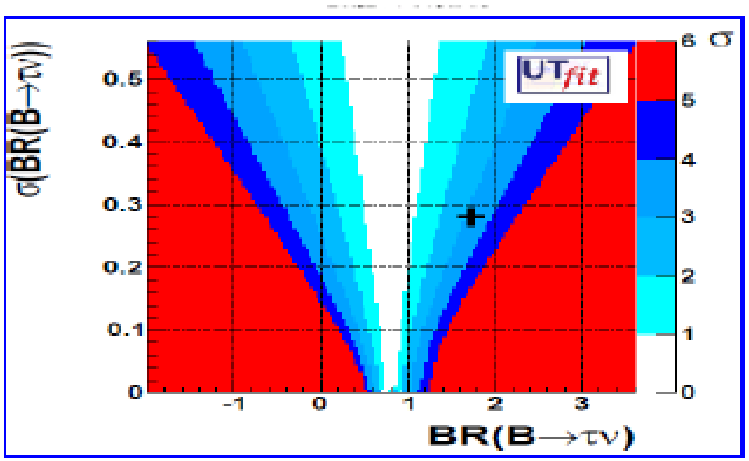
CKM fitter

$$Br_{CKM\ fit}(\tau\nu) = (0.763^{+0.113}_{-0.061}) \times 10^{-4}$$

UT fit

$$Br_{CKM\ fit}(\tau\nu) = (0.805 \pm 0.071) \times 10^{-4}$$



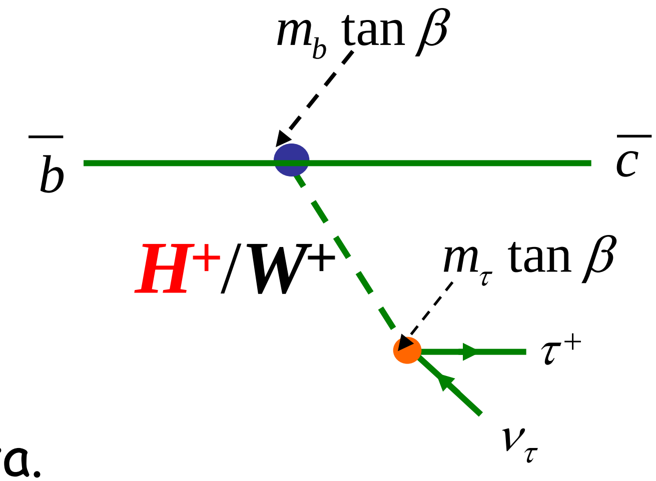


The measured Br is ~2.8 σ higher than the value predicted by the CKM fit.

$B \to D\ \tau\ \nu$

$B \to D\ \tau\ \nu$ is another process sensitive to the charged Higgs, and complementary to $B \to \tau\ \nu$.

- Relatively large Br ~0.8%
- Different theory systematics:
  - free from V_{ub} and f_B ambiguity.
  - depends on the $B \to D$ form factors, which can be deduced from $D\ l\ \nu$ data.

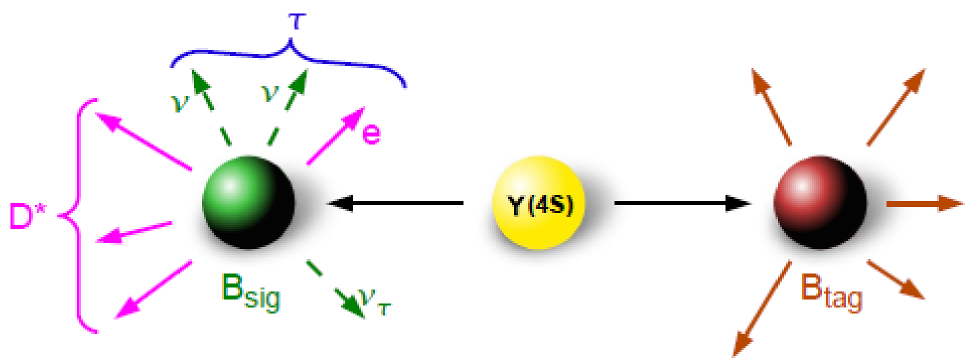


- Three-body decay permits the study of decay distributions which discriminate between W+ and H+ exchange. Also T polarization in $\tau \to \pi\ \nu$ mode.
- Universality between H-b-c, ($D\tau\nu$), H-b-u ($\tau\nu$), H-b-t (LHC).

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

- Inclusive B_{tag} reconstruction.
  - Calculate B_{tag} mass using 4 momentum vector of the tracks other than D* and (e, μ, π).

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



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

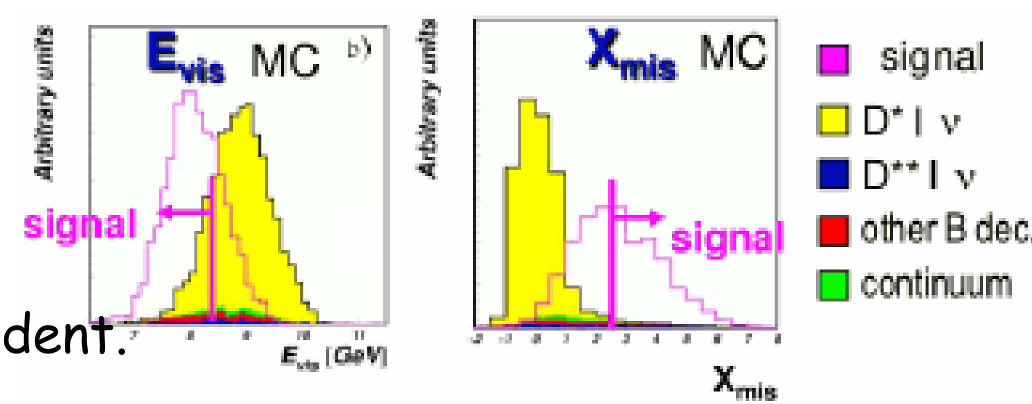
$\overline{D}^0 \to K^+\pi^-, \quad \overline{D}^0 \to K^+\pi^-\pi^0$

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

- Background suppresion
  - Visible energy
  - X_{mis}

$$X_{mis} = \frac{E_{mis} - \left|\vec{p}_{D^*} + \vec{p}_{\ell/\pi}\right|}{\left|\vec{p}_B\right|}$$

similar to M_{mis} but M_{tag} indepndent.

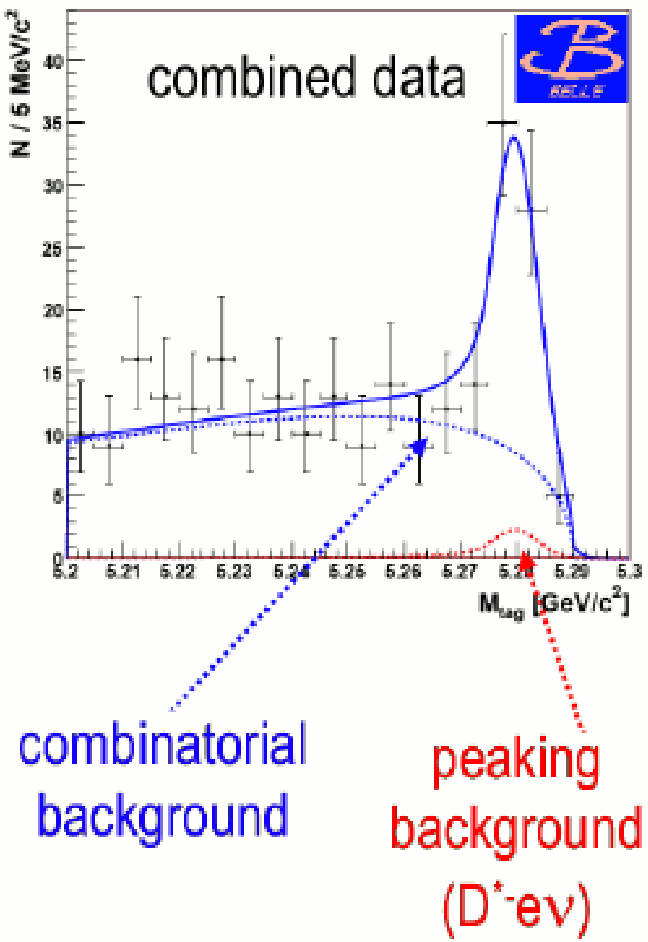


Belle $B \to D^{*-} \tau \nu$ (2007)

535M$B\bar{B}$

PRL **99, 191807 (2007)**

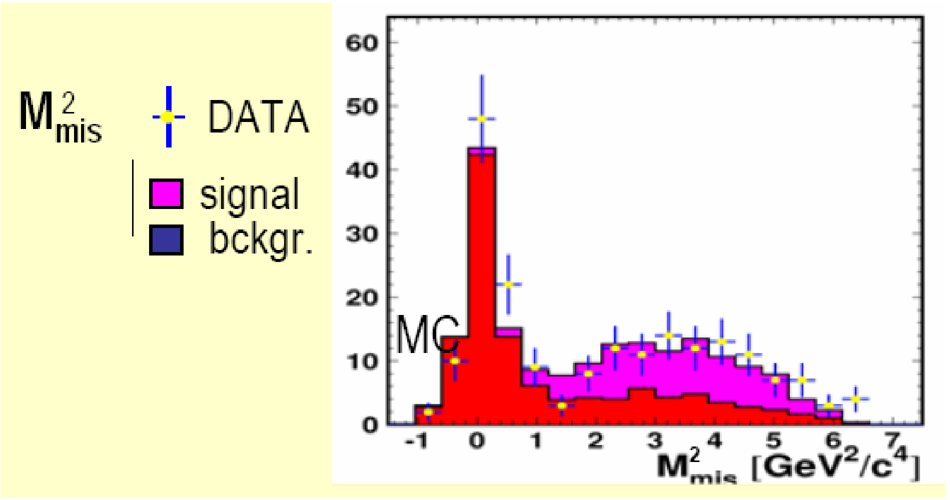
$$Br(B^0 \to D^{*-}\tau^+\nu_\tau) = (2.02^{+0.40}_{-0.37} \pm 0.37) \times 10^{-2}$$



$N_S = 60^{+12}_{-11}$

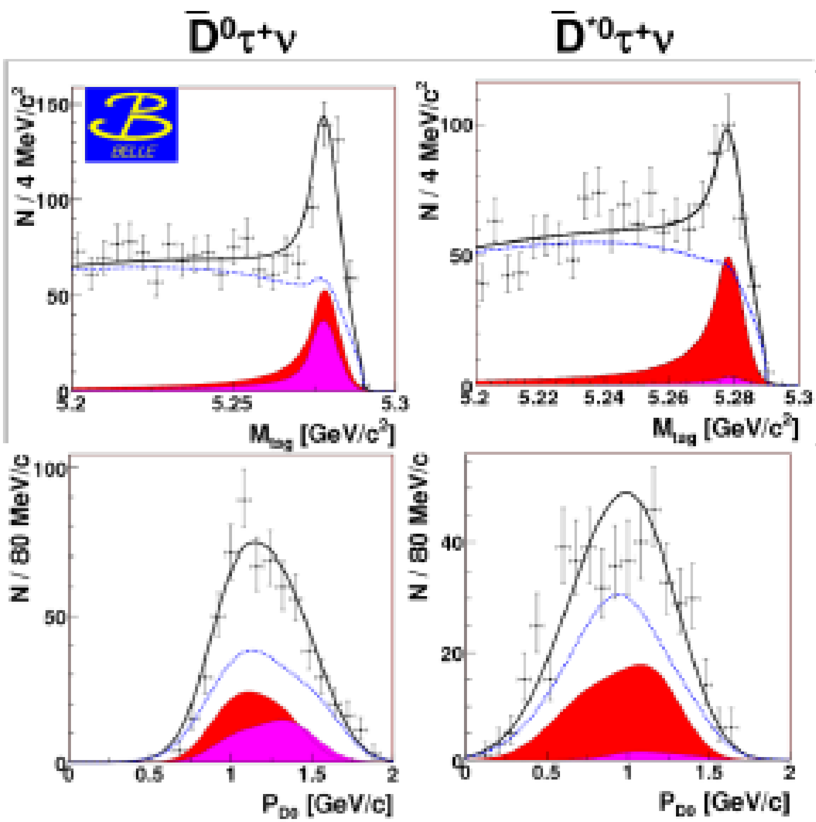
6.7σ (5.2σ w/ systematic)

First Observation



Belle B→D* τ ν (2010) 675M$B\bar{B}$

- Simultaneous extraction of signals in $B^+ \to D^{*0}\tau^+\nu$ and $B^+ \to D^{0+}\tau^+\nu$ *taking into* account D^{*0} <-> D^0 cross-feeds.
- Signal extraction from fit to 2-dim distributions in M_{tag} and $P_D{}^0$ (momentum of D^0 in Υ(4S) rest frame).
- Simultaneous fit to 13 decay chains with floating 2 signal BFs and 13 background normalizations



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

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

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

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

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

based on 675M $B\bar{B}$

hep-ex/1005.2302, submitted to PRL

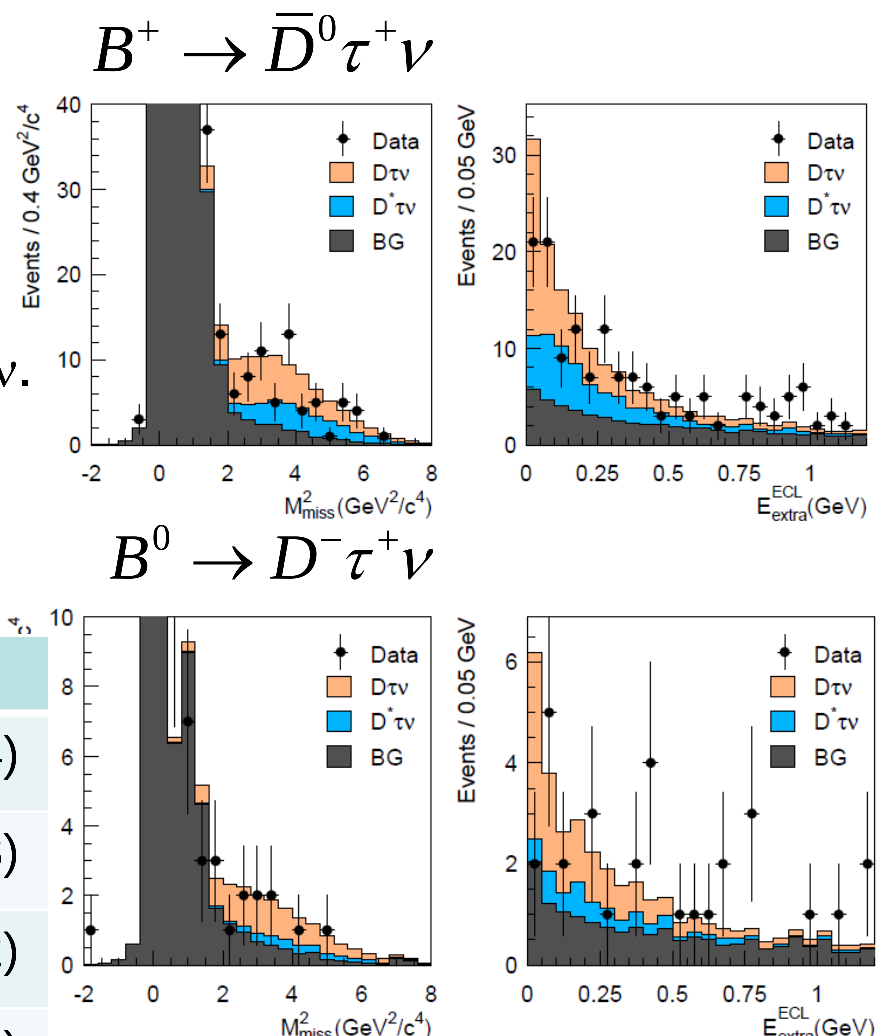
$B \to D\,\tau\,\nu$ w/ Hadronic Tag

- 657M $B\bar{B}$
- Hadronic tags.
- Extract signals in (MM^2, E_{ECL}) distribution.
- Simultaneous extraction of $D\tau\nu/D^*\tau\nu$.

$$R = \frac{Br(B \to D^{(*)}\tau\nu)}{Br(B \to D^{(*)}\ell\nu)}$$

	R(%)	Ns	Signif.
$D^0\,\tau\,\nu$	$70.2^{+18.9}_{-18.0}\,^{+11.0}_{-9.1}$	$98.6^{+26.3}_{-25.0}$	3.8(4.4)
$D^+\,\tau\,\nu$	$47.6^{+21.6}_{-19.3}\,^{+6.3}_{-5.4}$	$17.2^{+7.7}_{-6.9}$	2.6(2.8)
$D^{*0}\,\tau\,\nu$	$46.8^{+10.6}_{-10.2}\,^{+6.2}_{-7.2}$	$99.8^{+22.2}_{-22.3}$	3.9(5.2)
$D^{*+}\,\tau\,\nu$	$48.1^{+14.0}_{-12.3}\,^{+5.8}_{-4.1}$	$25.0^{+7.2}_{-6.3}$	4.7(5.9)

Belle preliminary

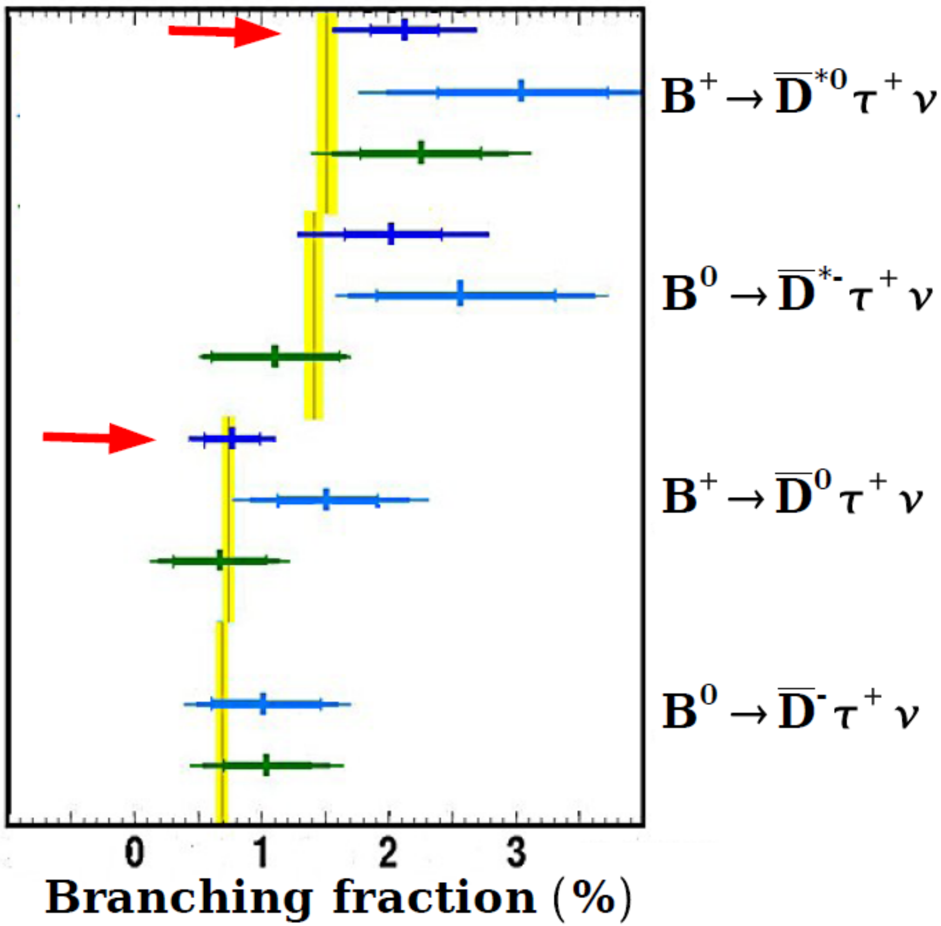


Dτν signal

D*τν cross talk

hep-ex/0910.4301

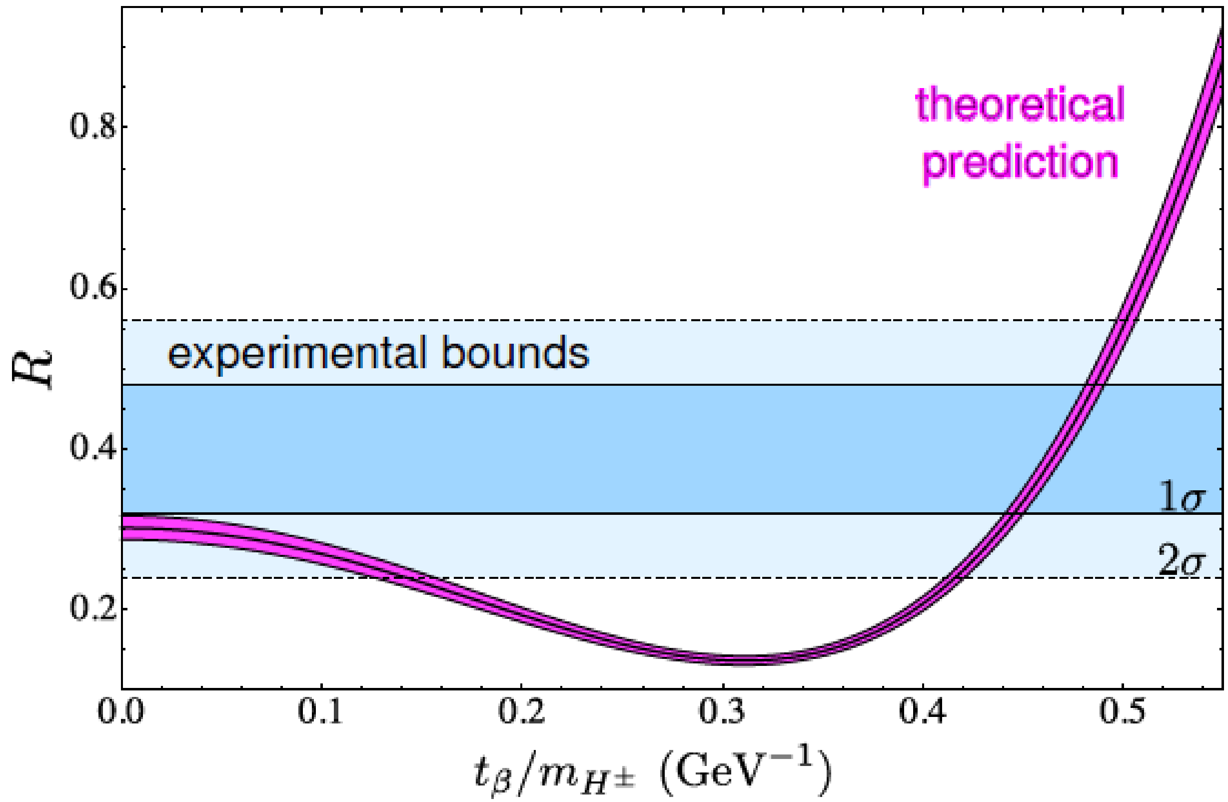
$B \rightarrow D^{(*)} \tau \nu$ Summary



Belle inclusive tag
PRL99, 191807 (2007)
arXiv:1005.2302
Belle hadronic tag
arXiv:0910.4301
BaBar hadronic tag
PRL100, 021801 (2008)

Constraint on Charged Higgs

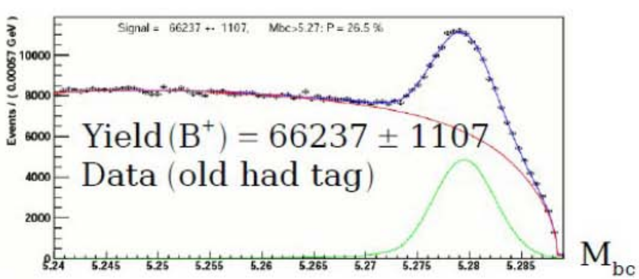
experimental bounds on $\tan\beta/m_H$ in type-II 2HDM from averaged Belle and BaBar measurements[10] of $R = \frac{\mathcal{B}(B\to D\tau\nu_\tau)}{\mathcal{B}(B\to Dl\nu_l)} = 0.40 \pm 0.08$

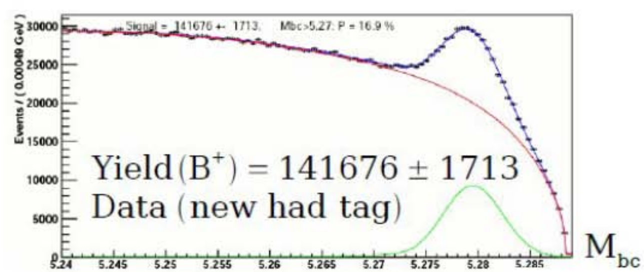


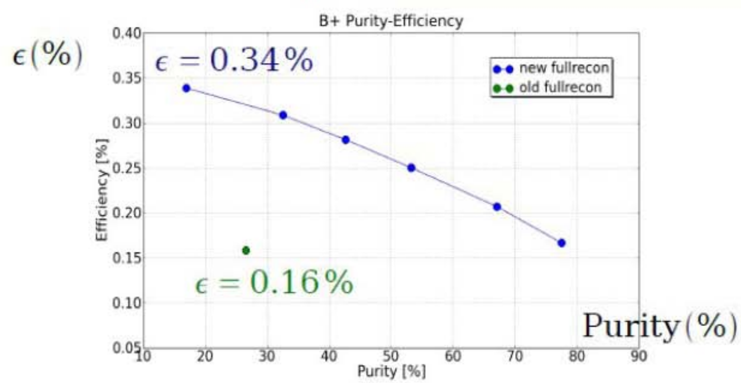
M. Tanaka, R. Watanabe, arXiv:1005.4306

Prospect

- Results using the full data set (~770M$B\bar{B}$)
  - Present results: w/ 449M $B\bar{B}$ for hadronic tag
    w/ 657M $B\bar{B}$ for semileptonic tag
  - Reprocessed with improved tracking efficiency
- Improvement for the hadronic tag
  ➡ effective luminosity improved by factor x2

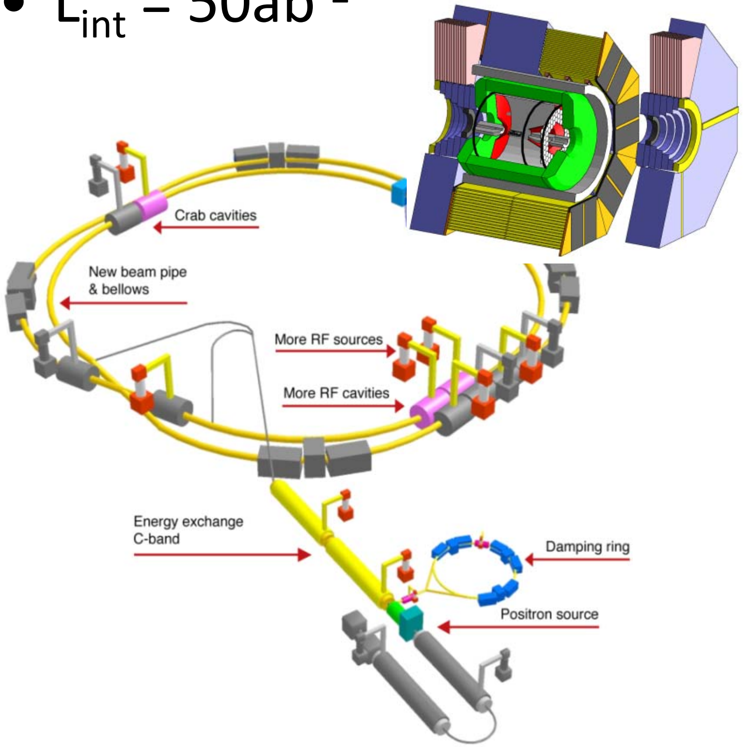




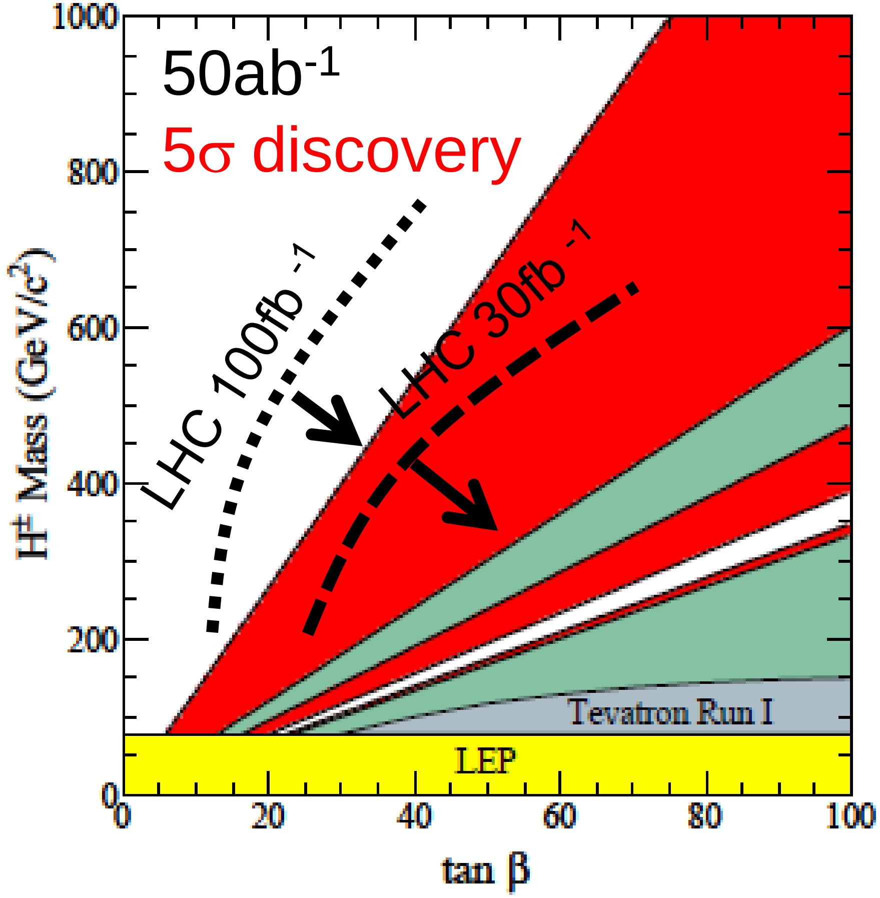


Prospect at Super-KEKB / Belle II

- 7GeV e^- × 4 GeV e^+
- L_{peak} = 8 × $10^{35}cm^{-2}s^{-1}$
- L_{int} = $50ab^{-1}$



Assume
Δexp ~ $1/\sqrt{L}$, $\Delta|V_{ub}|$ = Δf_B=2.5%



KEKB upgrade has been approved.

- 5.8 oku yen(MUSD) for damping ring (FY2010)
- 100 oku yen for machine.

“Very Advanced Research Support Program” (FY2010-2012)

Construction started !

Summary

- B decays to the τ lepton final states, $B \rightarrow \tau\nu$ and $B \rightarrow D\tau\nu$, are unique probe to New Physics.

- Belle has measured both $B \rightarrow \tau\nu$ and $B \rightarrow D\tau\nu$ decays.
  - $B \rightarrow \tau\nu$ w/ hadronic and semileptonic tags.
  - $B \rightarrow D\tau\nu$ w/ inclusive and hadronic tags.

  ➡ Significant constraints on the charged Higgs.

- Results using the full data set and improved tagging efficiency will come in the near future.

- Super-KEKB/Belle II will provide results with a few percent error, and will provide stringent test of NP.

Thank you !

Backup

Cont'd

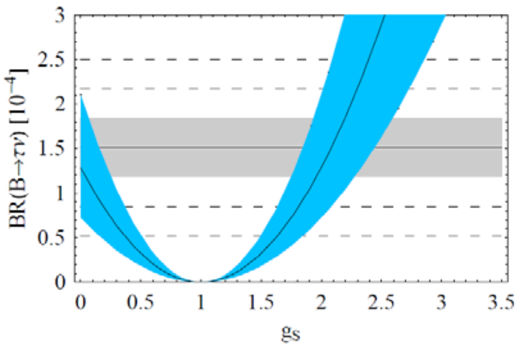
U. Nierste, S. Trine, S.Westhoff
PRD78, 015006 (2008).

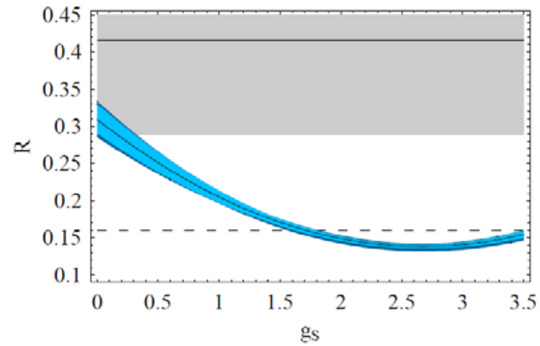
Effective scalar coupling;

$$\mathcal{B}(B \to D\tau\nu) \propto |V_{cb}|^2 \cdot f(F_V, F_S, g_S)$$

$$g_S = \frac{M_B^2 \tan^2\beta}{M_H^2} \frac{1}{(1+\varepsilon_0 \tan\beta)(1+\varepsilon_\tau \tan\beta)},$$

SUSY Loop correction
(ε_0=ε_τ=0 in Type-II 2HDM)

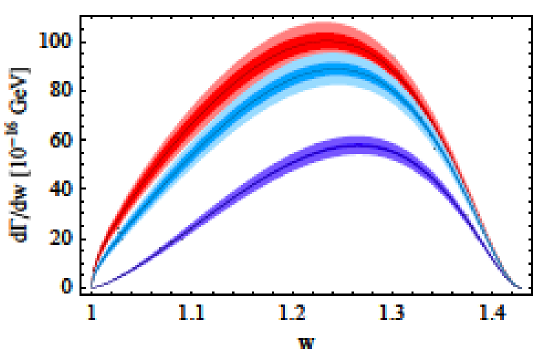




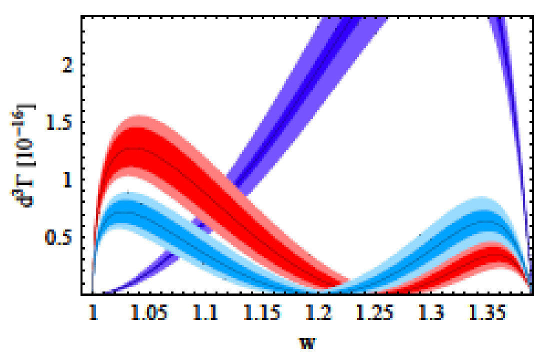
$$\frac{d\Gamma(B \to D\tau\nu)}{dw} \propto |V_{cb}|^2 \left\{ (w^2-1) F_V(w)^2 \rho_V(w) + F_S(w)^2 \left[1 - g_s \frac{q^2/m_B^2}{1-m_c/m_b}\right]^2 \rho_S(w) \right\}$$

$$w = \frac{E_D}{m_D} = \frac{m_B^2 + m_D^2 - q^2}{2 m_B m_D}$$

$d\Gamma(B \to D\tau\nu)/dw$



$d\Gamma(B \to D\nu\tau[\to \pi\nu])/dE_\pi d\cos\theta_{D\pi} dw$



$$E_\pi = 1.8\,\mathrm{GeV}$$

$$\cos\theta_{D\pi} = -1$$