Constraining charged Higgs bosons from measurements of $B^\pm \to \tau^\pm \nu / B_c^\pm \to \tau^\pm \nu$ at Giga Z

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- $B^\pm \to \tau^\pm \nu$ has been measured at e^+e^- B factories
- Important constraints on the parameter tan $\beta/m_{H^\pm}$
- Search for $B^\pm \to \tau^\pm \nu$ at LEP1 and contribution of $B_c^\pm \to \tau^\pm \nu$
- Measuring $B^\pm/B_c^\pm \to \tau^\pm \nu$ at Giga Z option of Linear Collider
- Comparison with a High Luminosity Flavour Factory ($B^\pm \to \tau^\pm \nu$)

A.G.A, Chuan-Hung Chen, S. Recksiegel: Phys.Rev.D77,115018 (2008) arXiv:0803.3517

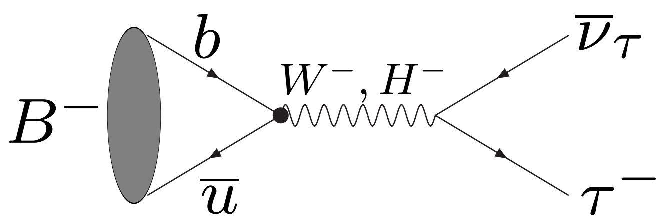
Talk at LC10, Frascati, 02 December 2010

The purely leptonic decays of pseudoscalar mesons, $M^\pm \to l^\pm \nu_l$

- Well-known examples are $\pi^\pm \to \ell^\pm \nu_\ell$ and $K^\pm \to \ell^\pm \nu_\ell$ $(\ell^\pm = e^\pm, \mu^\pm)$
- Measured in 1950s with large branching ratios

Heavier mesons: $D^\pm(\bar{c}d, c\bar{d})$, $D_s^\pm(\bar{c}s, c\bar{s})$, $B^\pm$ $(\bar{b}u, b\bar{u})$, $B_c^\pm$ $(\bar{b}c, b\bar{c})$

Proceed via annihilation of $M^\pm$ into $W^\pm$ and $\boxed{H^\pm \text{ (New Physics)}}$



Decay rate for $B^\pm \to l^\pm \nu_l$

$W^\pm$ and $H^\pm$ effectively induce the four-fermion interaction:

$$(G_F/\sqrt{2})V_{ub}\big([\overline{u}\gamma_\mu(1-\gamma_5)b][\bar{l}\gamma^\mu(1-\gamma_5)\nu] - Y[\overline{u}(1+\gamma_5)b][\bar{l}(1-\gamma_5)\nu]\big)$$

$Y = \tan^2\beta(m_b m_l/m^2_{H^\pm})$ for 2HDM (Model II) $\boxed{\tan\beta = v_2/v_1}$

The tree–level partial width is given by:

$$\Gamma(B^\pm \to l^\pm \nu_l) = \frac{G_F^2 m_B m_l^2 f_B^2}{8\pi}|V_{ub}|^2\left(1-\frac{m_l^2}{m_B^2}\right)^2 \times r_H$$

In SM $r_H = 1$; $|V_{ub}|$ is measured; f_B calculated in lattice QCD

With $H^\pm$, $r_H \neq 1$ and depends on $\tan\beta/m_{H^\pm}$

Effect of $H^\pm$ on $B^\pm \to \tau^\pm \nu_\tau$

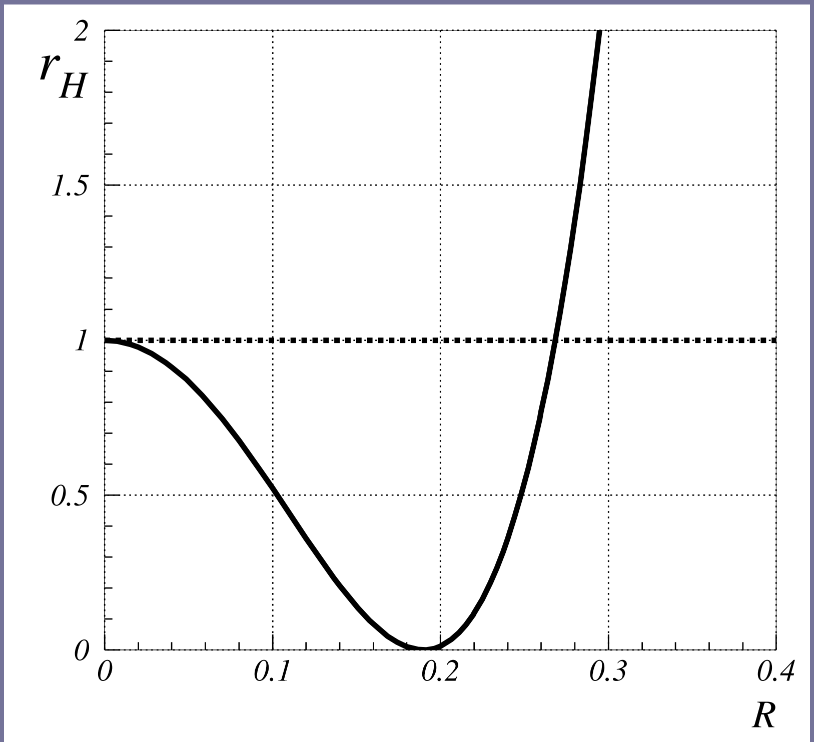
Scale factor r_H: W.S. Hou, Phys.ReV.D48,2342 (1993)

$$r_H = [1 - m_B^2 \frac{\tan^2\beta}{m_{H^\pm}^2}]^2 \equiv [1 - m_B^2 R^2]^2$$

- Same for each lepton flavour ($B^\pm \to e^\pm\nu, \mu^\pm\nu, \tau^\pm\nu$)
- Destructive interference
- Sensitivity to $\frac{\tan\beta}{m_{H^\pm}}(= R)$

These two parameters determine the tree-level MSSM Higgs potential

Scale factor r_H as a function of $R(=\tan\beta/m_{H^\pm})$



Two solutions for $r_H = 1$ i) $R = 0$ and ii) $R = 0.27\ \mathrm{GeV}^{-1}$

Search for $B^\pm \to \tau^\pm \nu_\tau$ at e^+e^- B factories

First observation of $B^\pm \to \tau^\pm \nu_\tau$ by BELLE in 2006:

K.Ikado et al, Phys.Rev.Lett.97:251802 (2006); using 450×10^6 $B^\pm$s

$$\mathrm{BR}(B^\pm \to \tau^\pm \nu_\tau) = (1.79^{+0.56}_{-0.49}(stat)^{+0.46}_{-0.51}(syst)) \times 10^{-4}$$

In agreement with SM prediction

Has become an important constraint on the parameter space of

$[\tan\beta, m_{H^\pm}]$ in 2HDM Hou 93 and MSSM AGA/Recksiegel 03; Isidori/Paradisi 06

Constraint on scale factor r_H and $\tan\beta/m_{H^\pm}$

Main uncertainty in SM prediction for $\mathrm{BR}(B^\pm \to \tau^\pm \nu_\tau)$

comes from $|V_{ub}|$ and f_B

- $|V_{ub}|$ measured from inclusive/exclusive decays with $b \to uW^*$

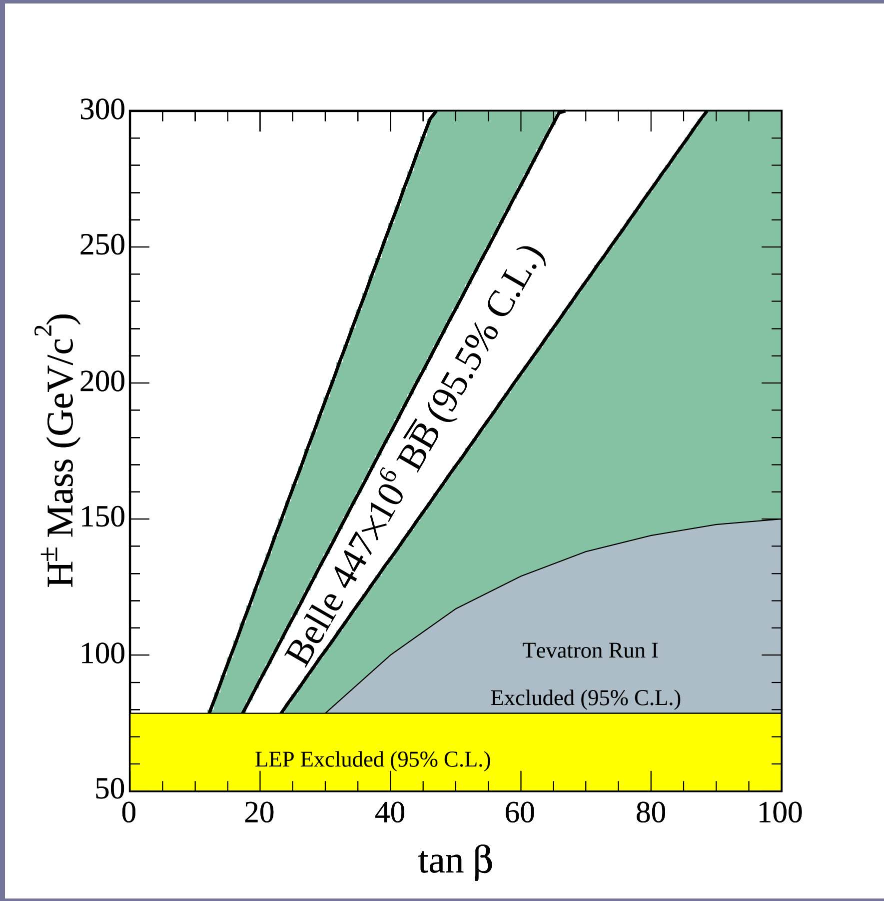
$\boxed{|V_{ub}| = (3.92 \pm 0.09 \pm 0.45) \times 10^{-3}}$ average of exclusive/inclusive $|V_{ub}|$ (disagreement)

- $f_B = 192 \pm 9.9$ MeV (average of two unquenched lattice QCD calculations)

Measurement of r_H has error from $|V_{ub}|$, f_B and exp error in measurement of $\mathrm{BR}(B^\pm \to \tau^\pm \nu_\tau)$

$$r_H = [1 - m_B^2 \frac{\tan^2\beta}{m_{H^\pm}^2}]^2 = 1.62 \pm 0.57$$

Constraint on r_H and plane $[\tan\beta, m_{H^\pm}]$ using BELLE 2006 measurement



Green region ruled out. Comparable constraints to those from direct production of $H^\pm$ at LHC

Current measurements of $B^\pm \to \tau^\pm \nu_\tau$ at e^+e^- B factories

Four measurements (BELLE and BABAR):BR in units of 10^{-4}

$\boxed{e^+e^- \to B^+B^-;\ B^+ \to \tau^+\nu}$; $B^- \to$ hadronic or semileptonic (and vice versa)

- BELLE 450×10^6 $B^\pm$ (hadronic tag): $1.79^{+0.56}_{-0.49}{}^{+0.46}_{-0.51}$
- BELLE 657×10^6 $B^\pm$ (semileptonic tag): $1.54^{+0.38}_{-0.37}{}^{+0.29}_{-0.31}$
- BABAR 467×10^6 $B^\pm$ (hadronic tag): $1.8^{+0.57}_{-0.54} \pm 0.26$
- BABAR 460×10^6 $B^\pm$ (semileptonic tag): $1.7 \pm 0.8 \pm 0.2$

World average of BR($B^\pm \to \tau^\pm \nu_\tau$)= $\boxed{1.64 \pm 0.34 \times 10^{-4}}$ HFAG

Future measurements of $B^\pm \to \tau^\pm \nu$

$B^\pm \to \tau^\pm \nu$ plays a prominent role in the physics case for a

High Luminosity B Factory

- Greater precision for BR($B^\pm \to \tau^\pm \nu$) is desirable

$\to$ constraints on $[\tan\beta, m_{H^\pm}]$ complementary

to those from direct production of $H^\pm$ at the LHC

- Upgrade of KEK-B and BELLE detector has been approved
- Flavour physics factory in Europe?
- Would give precision of maybe 5% for BR($B^\pm \to \tau^\pm \nu$)

(and similar precision for BR($B^\pm \to \mu^\pm \nu$))

Measuring $B^{\pm} \to \tau^{\pm}\nu$ and $B_c^{\pm} \to \tau^{\pm}\nu$ at the Z peak: LEP1 and Giga Z

AGA/Chen/Recksiegel: Phys.Rev.D77, 115018 (2008)

Measuring $B^{\pm} \to \tau^{\pm}\nu$ at the Z peak ($\sqrt{s} = 91$ GeV)

- LEP1 (DELPHI, ALEPH, L3) also searched for $B^{\pm} \to \tau^{\pm}\nu$
- Used $Z \to b\overline{b}$ decays. Strongest limit from L3 (1997)

BR($B^{\pm} \to \tau^{\pm}\nu$) $< 5.7 \times 10^{-4}$ (current world average $\boxed{1.64 \pm 0.34 \times 10^{-4}}$)

- L3 only used half their data. Is a reanalysis of interest?
- Z-peak data sensitive to $\boxed{B^{\pm} \to \tau^{\pm}\nu \text{ and } B_c^{\pm} \to \tau^{\pm}\nu}$
- Have (almost) the same signature

$\rightarrow$ limit on BR applies to sum of both decays

Contribution of $B_c^\pm \to \tau^\pm\nu$ to measurement of $B^\pm \to \tau^\pm\nu$

- $B_c^\pm$ (bc) meson discovered in 1998 at the Tevatron Run I

Ratio of $\tau^\pm\nu$ events from $B^\pm \to \tau^\pm\nu$ (N_u) and $B_c^\pm \to \tau^\pm\nu$ (N_c) given by:

$$\frac{N_c}{N_u} = \left|\frac{V_{cb}}{V_{ub}}\right|^2 \frac{f(b \to B_c^\pm)}{f(b \to B^\pm)} \left(\frac{f_{B_c}}{f_B}\right)^2 \frac{M_{B_c}}{M_B}\frac{\tau_{B_c}}{\tau_B}\frac{\left(1 - \frac{m_\tau^2}{M_{B_c}^2}\right)^2}{\left(1 - \frac{m_\tau^2}{M_B^2}\right)^2}$$

- $f(b \to B_c^\pm) \sim 0.001(?)$ and $f(b \to B^\pm) \sim 0.38$ (transition probabilities)
- $V_{cb}(\sim 0.04) \gg V_{ub}(\sim 0.004)$ compensates for small $f(b \to B_c^\pm)$

Magnitude of $B_c^\pm \to \tau^\pm \nu$ contribution

How large can N_c/N_u be? How does N_c affect LEP limits on $B^\pm \to \tau^\pm \nu$? Mangano/Slabospitsky 97

- N_u is known quite well (main uncertainty from f_B and V_{ub})
- Much larger uncertainty for N_c

i) $\boxed{\text{Decay constant } f_{B_c}}$ $400 MeV < f_{B_c} < 600 MeV$?

Only one (?) quenched lattice calculation: $f_{B_c} = 489 \pm 5$ MeV TWQCD Collaboration 07

ii) $\boxed{\text{Transition probability}}$ $f(b \to B_c^\pm)$

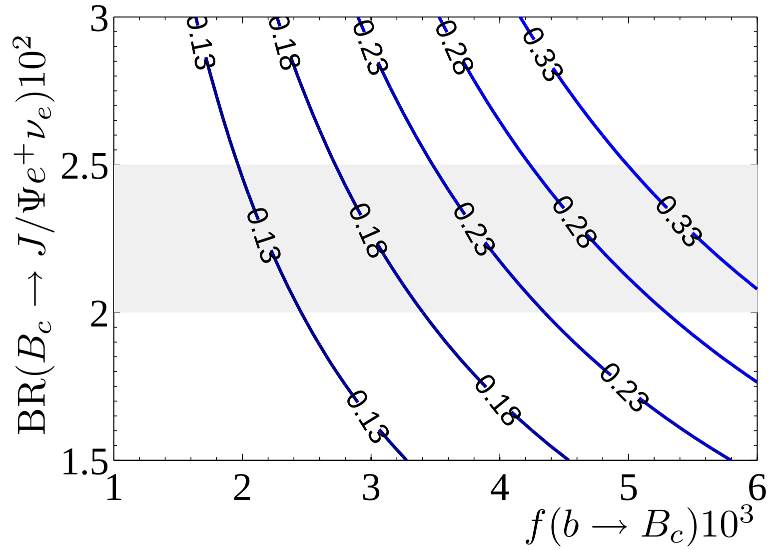
Transition probability $f(b \to B_c^{\pm})$

- $f(b \to B_c^{\pm})$ is now being measured at the Tevatron
- Can be determined from $\mathcal{R}_\ell = \frac{\sigma(B_c^{+})\cdot\mathrm{BR}(B_c^{\pm}\to J/\psi\ell^{\pm}\nu_\ell)}{\sigma(B^{+})\cdot\mathrm{BR}(B^{\pm}\to J/\psi K^{\pm})}$
- $\boxed{\sigma(B^{+}) \cdot \mathrm{BR}(B^{\pm} \to J/\psi K^{\pm})}$ already determined by experiment
- $B_c^{\pm} \to J/\psi\ell^{\pm}\nu_\ell$ is predicted by theory
- $f(b \to B_c^{\pm})$ can be extracted from $\mathcal{R}_\ell$
- $\mathcal{R}_\ell$ is measured in two channels:

i) $B_c^{\pm} \to J/\psi e^{\pm}\nu_e$: $\boxed{\mathcal{R}_e = 0.28 \pm 0.07}$ with 0.36 fb^{-1}

ii) $B_c^{\pm} \to J/\psi \mu^{\pm}\nu_\mu$: $\boxed{\mathcal{R}_\mu = 0.29 \pm 0.07}$ with 1 fb^{-1}

Contours of $\mathcal{R}_\ell$ in the plane of BR($B_c \to J/\psi e^+ \nu_e$) and transition probability $f(b \to B_c)$.



$\mathcal{R}_\ell = 0.28$ suggests $0.004 < f(b \to B_c) < 0.005$ (larger than expected value)

Number of $\tau^{\pm}\nu$ events from $B^{\pm}/B_c^{\pm} \to \tau^{\pm}\nu$

LEP limits constrain "effective branching ratio"

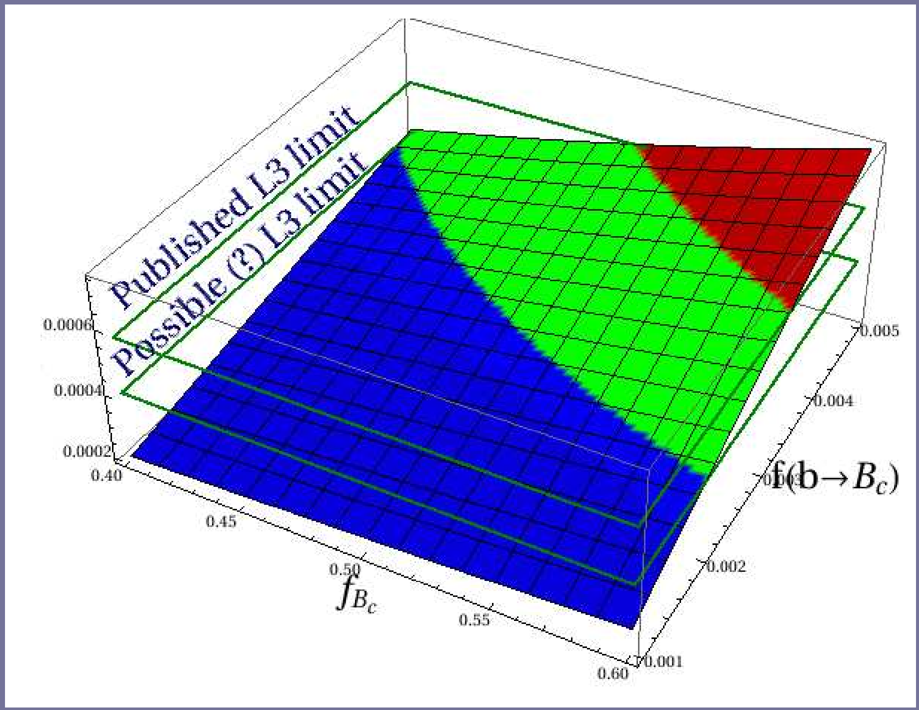
Number of $\tau^{\pm}\nu$ originating from $B_c^{\pm} \to \tau^{\pm}\nu$ and $B^{\pm} \to \tau^{\pm}\nu$

can be written as $\sigma_{B^{\pm}} \times \mathrm{BR}_{\mathrm{eff}}$ where:

$$\boxed{\mathrm{BR}_{\mathrm{eff}} = \mathrm{BR}(B^{\pm} \to \tau^{\pm}\nu)\left(1 + \frac{N_c}{N_u}\right)}$$

$N_c = 0$ gives $\sigma_{B^{\pm}} \times BR(B^{\pm} \to \tau^{\pm}\nu)$

Effective BR($B^\pm/B_c^\pm \to \tau^\pm\nu$) in the plane $[f(b \to B_c^\pm), f_{B_c}]$



Red region ($\mathrm{BR}_{\mathrm{eff}} > 5.7 \times 10^{-4}$) ruled out by L3. Green region denotes $4 \times 10^{-4} < \mathrm{BR}_{\mathrm{eff}} < 5.7 \times 10^{-4}$

Use of LEP (L3 Collaboration) data for $B^\pm/B_c^\pm \to \tau^\pm\nu$

Current limit on $B^\pm/B_c^\pm \to \tau^\pm\nu$ set with $1.5 \times 10^6\ Z$ bosons

- Constrains the plane $[f_{B_c}, f(b \to B_c^\pm)]$
- Only experimental information on f_{B_c}
- L3 recorded $3.6 \times 10^6\ Z$ bosons. Reanalysis might:

i) See signal for $B^\pm/B_c^\pm \to \tau^\pm\nu$ (first observation of $B_c^\pm \to \tau^\pm\nu$)

i) Central values of f_{B_c} (lattice) and $f(b \to B_c^\pm)$ (Tevatron) suggest $\mathrm{BR_{eff}} > 4 \times 10^{-4}$, which is reachable(?)

Prospects at Linear Collider Z peak option

- Has the option of running at the Z peak ("Giga Z option")
- Such operation would be beneficial for checking detector performance (i.e. reproducing and improving LEP1 results)
- High luminosity version of LEP1
- $10^9 Z$ bosons in a few months (LEP1 $\sim 3 \times 10^6$/experiment)
- Measuring $B^{\pm}/B_c^{\pm} \to \tau^{\pm}\nu$ does not need polarised beams

Comparison of Super B and Giga Z

- Historically, limits on $B^{\pm} \to \tau^{\pm}\nu$ from Z peak are comparable with limits from $\Upsilon(4S)$ data for similar number of Z and $B^{\pm}$

- CLEO limit $\mathrm{BR}(B^{\pm} \to \tau^{\pm}\nu) < 8.4 \times 10^{-4}$ with 9.7×10^{6} $B^{\pm}$
- L3 limit $\mathrm{BR}(B^{\pm} \to \tau^{\pm}\nu) < 5.7 \times 10^{-4}$ with 1.5×10^{6} Z
- Assume signal of $\mathrm{BR}_{eff} = 4 \pm 2 \times 10^{-4}$ at L3

Error $\mathrm{BR}(B^{\pm}/B_c^{\pm} \to \tau^{\pm}\nu)$	High Lum. B Factory (B mesons)	Giga Z (Z bosons)
20%	2.2×10^{9}	3.2×10^{7}
4%	8.1×10^{10}	8×10^{8}

- Can offer precision competitive with high-luminosity B factory

Constraining $\tan\beta/m_{H^\pm}$ from BR$_{\text{eff}}$ at Giga Z

Main uncertainty in contribution of N_c to BR$_{\text{eff}}$ will be substantially reduced by time of operation of Giga Z:

i) f_{B_c}: precise unquenched lattice QCD calculations

ii) Transition probability $f(b \to B_c^\pm)$

$\to$ expect improved measurements from Tevatron and LHC-b

Scale factor r_H from $H^\pm$ contribution almost the same Du/Jin/Yang 97

i) $r_H = [1 - m_B^2 \frac{\tan^2\beta}{m_{H^\pm}^2}]^2$ for $B^\pm \to \tau^\pm \nu$ ($m_B = 5.3$ GeV)

ii) $r_H = [1 - m_{B_c}^2 \frac{\tan^2\beta}{m_{H^\pm}^2}]^2$ for $B_c^\pm \to \tau^\pm \nu$ ($m_{B_c} = 6.4$ GeV)

Conclusions

- $B^\pm \to \tau^\pm \nu$ has been measured at e^+e^- B factories
- Important constraints on the parameter $\tan\beta/m_{H^\pm}$

(competitive with and complementary to direct $H^\pm$ production at LHC)

- At Z peak (LEP1 and Giga Z) $B_c^\pm \to \tau^\pm \nu$ contributes to the measurement of $B^\pm \to \tau^\pm \nu$
- L3 (LEP) might see signal for $\boxed{B^\pm/B_c^\pm \to \tau^\pm \nu}$ if all data used
- Giga Z option of Linear Collider could measure $B^\pm/B_c^\pm \to \tau^\pm \nu$ with precision comparable to that at High-Luminosity B factories
- Giga Z would provide an additional indirect probe of $\tan\beta/m_{H^\pm}$

$\boxed{\text{Origin of } m_l \text{ dependence}}$

Both $W^{\pm}$ and $H^{\pm}$ contribution proportional to m_l

but for $\boxed{\text{different reasons}}$

Angular momentum conservation requires that both

$l^{\pm}$ and ν have the same helicities, $l^-_R \overline{\nu}_R$ and $l^+_L \nu_L$

- $\boxed{W^- \text{ mediated diagram}}$ produces $l^-_L \overline{\nu}_R$

$\longrightarrow$ m_l helicity suppression from $l^-_L \rightarrow l^-_R$

- $\boxed{H^- \text{ contribution}}$ produces $l^-_R \overline{\nu}_R$.

$\longrightarrow$ m_l originates from Yukawa coupling