Charged Higgs Studies

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Outline

- Charged Higgs from top-quark decay in large extra dimensions
- Charged Higgs in the transition region: $m_{H^\pm} \sim m_t$
- Prospects for $H^\pm$ couplings determination

$t \to bH^{\pm}(\to \tau\psi)$ in LED

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- In the SM, $t \to Wb$ with ∼100% branching
- In supersymmetric models,

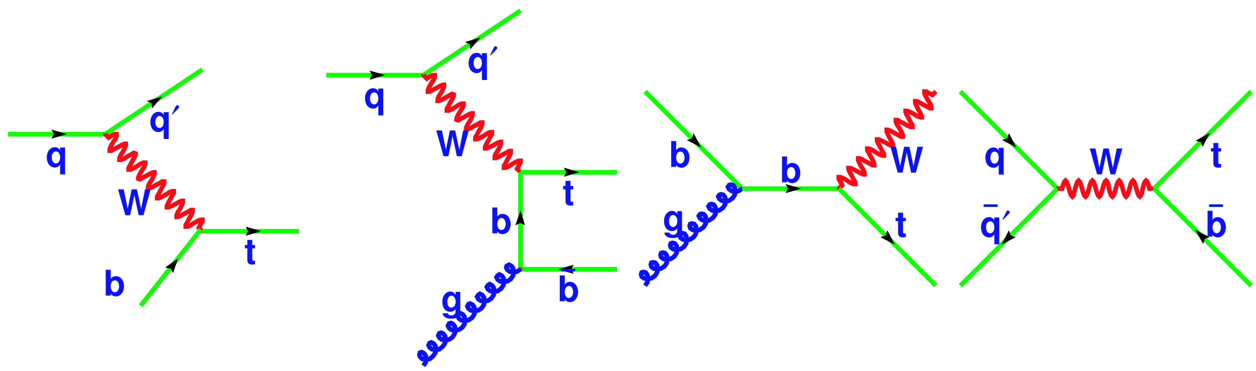
$$\begin{aligned} t &\to W^{\pm}b \\ t &\to H^{\pm}b \\ t &\to \tilde{t}\tilde{\chi}_i^0 \end{aligned}$$

- In large extra dimensions, $H^- \to \tau^-\psi$ can be enhanced due the large number of KK modes of the bulk neutrino ψ
- In models with FCNC or LFV at tree level (for instance 2HDM-III): $t \to c\gamma$, $t \to cZ$, $t \to c\,h$

⇒ A model independent measurement of Γ_t may signal new physics
⇒ measurements of $BR(t \to Wb)$, V_{tb} and Γ_t are of prime importance.

The Case of the SM

$\Gamma(t \rightarrow Wb)$ can be extracted from single top quark production



$$\sigma_{Wg} \text{ and } \sigma_{W*} \propto \Gamma(t \rightarrow Wb)$$

By measuring $BR(t \rightarrow Wb)$ in $gg \rightarrow t\bar{t}$,

$$\Gamma_t = \frac{\Gamma(t \rightarrow Wb)}{BR(t \rightarrow Wb)}$$

$BR(t \rightarrow Wb)$ measured in $t\bar{t}$ events using ratios of BRs:

- lepton+jets sample: ratio of single to double b-tags: $\frac{BR(t \rightarrow Wb)}{BR(t \rightarrow Wq)}$
- Ratio of single to di-lepton events: $\frac{BR(t \rightarrow Wq)}{BR(t \rightarrow non-W+X)}$

The Case of the 2HDM-I, II

- If kinematically allowed, $t \rightarrow bH^{+}$ would compete with $t \rightarrow bW^{+}$
- $\Gamma\left(t \rightarrow bW^{+}\right)$ is unchanged $\Rightarrow$ W-gluon fusion process is not modified
- $\Rightarrow$ One can extract Γ_{t} in the same way as in the SM case,i.e., getting $\Gamma\left(t \rightarrow Wb\right)$ from the measured cross section and $BR\left(t \rightarrow Wb\right)$ from $t\bar{t}$ events
- Excess of τ leptons from $H^{\pm} \rightarrow \tau^{\pm}\nu_{\tau}$ $\Rightarrow$ violation of lepton universality in the top quark sector.

The Case of Large Extra Dimensions

- Assume no additional Higgs bosons other than those of 2HDM-I or II
- $H^\pm$ production mechanisms:
  - $m_{H^\pm} > m_t$: $gb \to tH^\pm$ and $gg \to tbH^\pm$
  - $m_{H^\pm} \sim m_t$: $gg \to tbH^\pm$
  - $m_{H^\pm} < m_t$: $t \to bH^\pm$
- In 2HDM-II,

$$H^- \to \tau_R^- \bar{\nu},$$

  H^- to τ_L^- suppressed

- In Large Extra Dimensions, $H^- \to \tau_L^- \psi$ can be enhanced by large number of KK states. Thus,

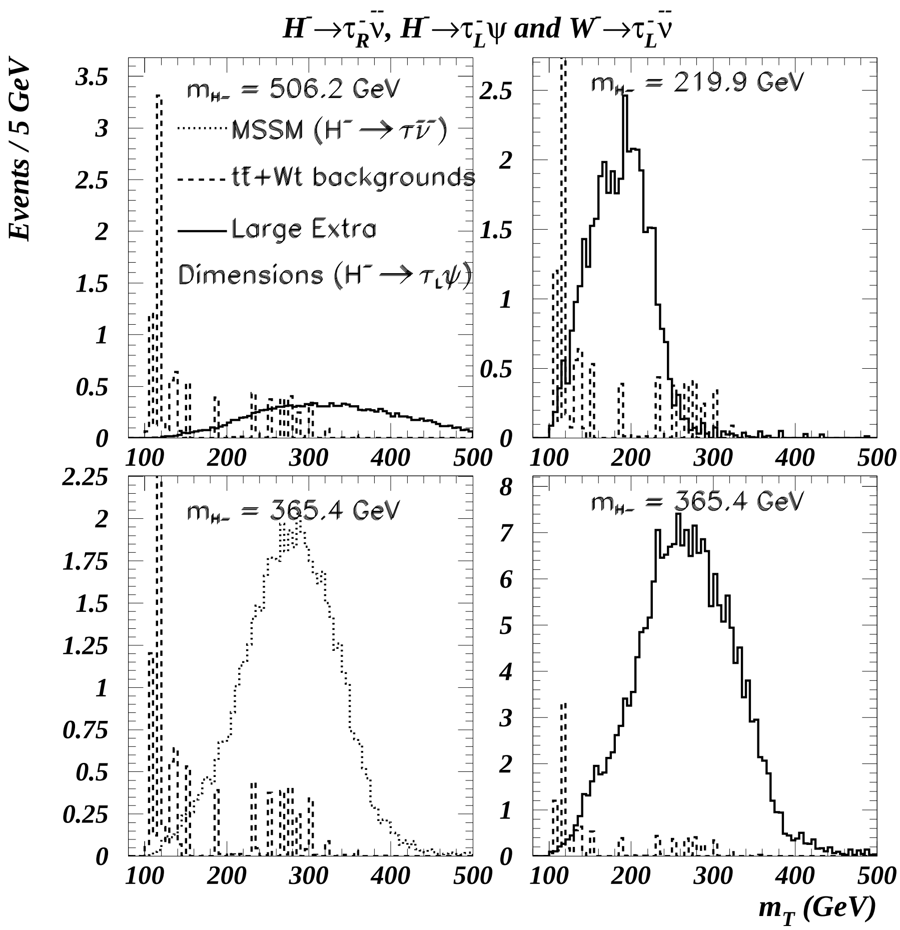
$$H^- \to \tau_R^- \bar{\nu} + \tau_L^- \psi$$

  with an asymmetry depending on the parameters M_*, δ_ν, δ, m_D, $\tan\beta$ and $m_{H^\pm}$.

$H^- \to \tau_L^- \psi + c.c.$

$m_{H^\pm} > m_t$ $H^- \to \tau_L^- \psi$ at the LHC: Assamagan & Deandrea, Phy. Rev. D65 076006 (2002)

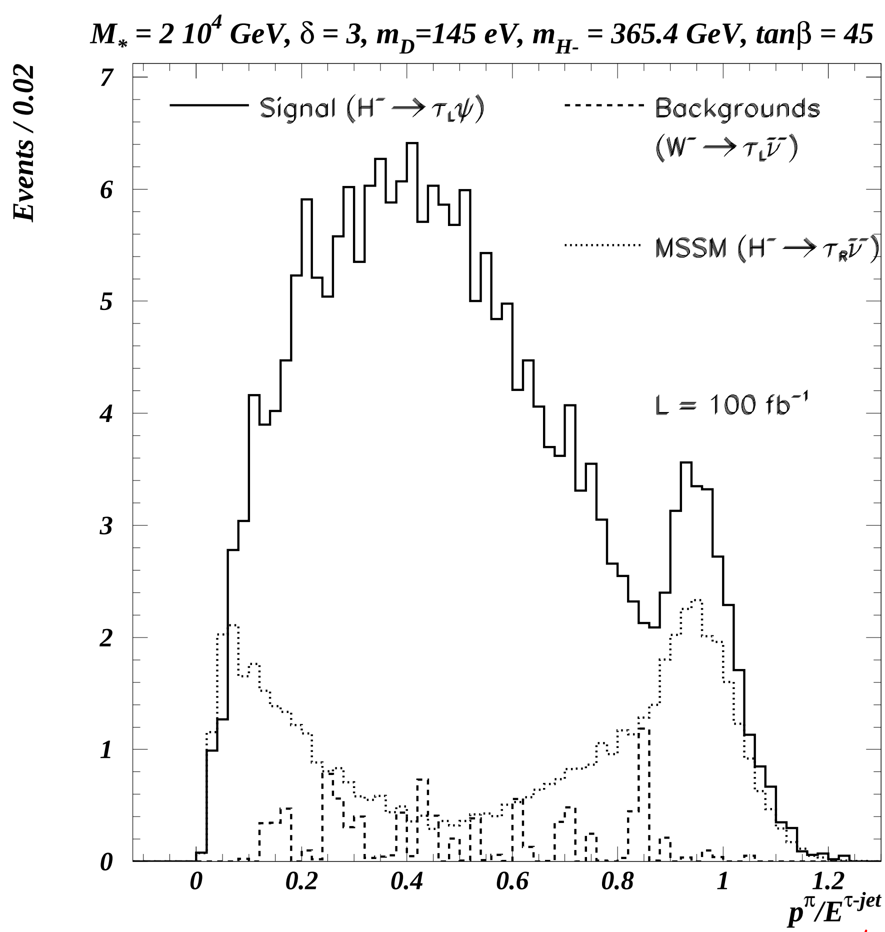
$$m_T = \sqrt{2p_T^\tau \not{p}_T \left[1 - \cos(\Delta\phi)\right]}$$



⇒ Observation of signal in m_T distribution is not sufficient to distinguish between 2HDM (MSSM) and L.E.D.

$$H^- \rightarrow \tau_L^- \psi + c.c.$$

Additionally, reconstruct the fraction of energy carried by the charged track in 1-prong τ decays



$\Rightarrow$ The reconstruction of m_T and of $p^\pi/E^{\tau-jet}$ should determine the scenario: 2HDM (MSSM) or L.E.D.

Further measurement of the asymmetry may provide a distinctive signature for L.E.D.

The Case of Large Extra Dimensions

$$m_{H^\pm} < m_t$$

- Enhancement of $H^- \to \tau_L^- \psi$ due to KK modes
- $H^- \to \tau_R^- \bar{\nu} + \tau_L^- \psi$
- Effectively, this means one additional decay mode of the top quark:

$$\bar{t} \to \bar{b}\tau_L\psi$$

mediated by the $H^\pm$

$$\Gamma(t \to bW^+) \approx \frac{G_F m_t^3}{8\pi\sqrt{2}} |V_{tb}|^2 (1 - x_W^2)(1 + x_W^2 - 2x_W^4)$$

$$\Gamma(\bar{t} \to \bar{b}\tau_L\psi) \sim \frac{\sqrt{2}G_F m_t^3}{192\pi^3} \cot^4\beta \left(\frac{m}{v}\right)^2 \left(\frac{m_t}{m_{H^\pm}}\right)^4 \times \left(\frac{m_t}{M_*}\right)^\delta \left(\frac{M_{Pl}}{M_*}\right)^2$$

The Case of Large Extra Dimensions

$$m_{H^\pm} < m_t$$

$$\frac{\Gamma(\bar{t} \to \bar{b}\tau_L\psi)}{\Gamma(t \to b\tau^+\nu)} \sim \frac{9\sqrt{2}}{0.624\pi^2} \cot^4\beta \left(\frac{m}{v}\right)^2 \times \left(\frac{m_t}{m_{H^\pm}}\right)^4 \left(\frac{m_t}{M_*}\right)^\delta \left(\frac{M_{Pl}}{M_*}\right)^2$$

Example:

$m^2 \sim 10^{-2}$ (eV)^2, $\tan\beta \sim 2$, $M_* \sim 2$ TeV, $\delta = 3$ and $m_{H^\pm} \sim 200$ GeV $\Rightarrow$ an enhancement of 100%!

- If $m_{\nu_e} \sim m_{\nu_\mu} \sim m_{\nu_\tau}$, then similar enhancement in $t \to be^+\nu_e$ and $t \to b\mu^+\nu_\mu$ otherwise these 2 would be unaffected $\Rightarrow$ violation of lepton universality.
- Measuring top BRs and Γ_t to $\sim 10\%$ may allow to see this effect!
- Measuring Γ_t: same technique as in the 2HDM without large extra dimensions and as in the SM case because $\Gamma\,(t \to W^+b)$ remains unaffected here too.

The Case of FCNC and LFV

As a example, we take the 2HDM-III where no discrete symmetry suppresses FCNC nor LFV processes at tree level

- $t \rightarrow ch$ $(h = h^0, H^0, A^0)$
- $t \rightarrow cg$, $t \rightarrow c\gamma$, $t \rightarrow cZ$
- This list of FCNC and LFV processes of the top quark is not exhaustive!
- the W-gluon fusion process may not be used any longer as a direct measure of $\Gamma\,(t \rightarrow Wb)$ because of additional contributions such as a t-channel $qq' \rightarrow ct$ mediated by a Z
- The s-channel W^* may also be affected by s-channel $q\bar{q} \rightarrow t\bar{c}$.
- The $W - t - b$ vertex may be affected $\Rightarrow$ all 3 modes of single top affected but $BR(t \rightarrow W^+b) \approx SM$ value. Measuring Γ_t same as in SM.

The Plan/Proposal

- Study the prospects for measuring Γ_t at the LHC:

  (a) Determine $\Gamma\left(t \rightarrow W^+b\right)$ from the measured Wg and $W*$ cross sections. The uncertainty in the cross section is the uncertain in $\Gamma\left(t \rightarrow W^+b\right)$

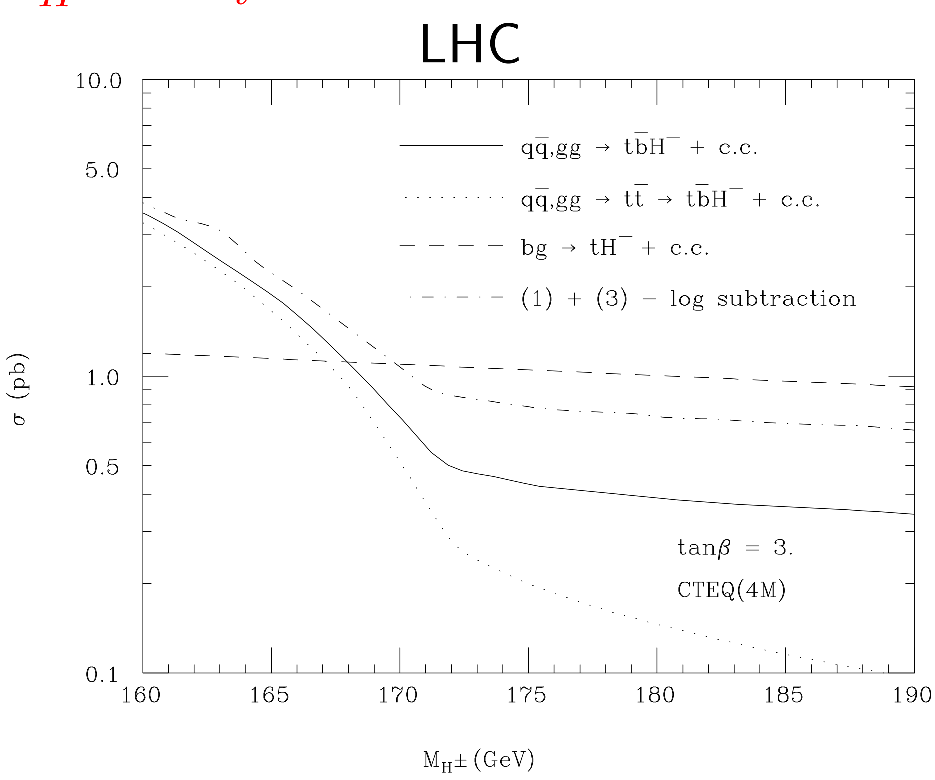
  (b) Determine $BR(t \rightarrow W^+b)$ from ratios of BRs in $t\bar{t}$ events

  (c) Determine Γ_t from **(a)** and **(b)**.

- The above method should be valid for the SM, the 2HDM-I and II and large extra dimensions assuming no FCNC and LFV

$H^{\pm}$ in Transition Region

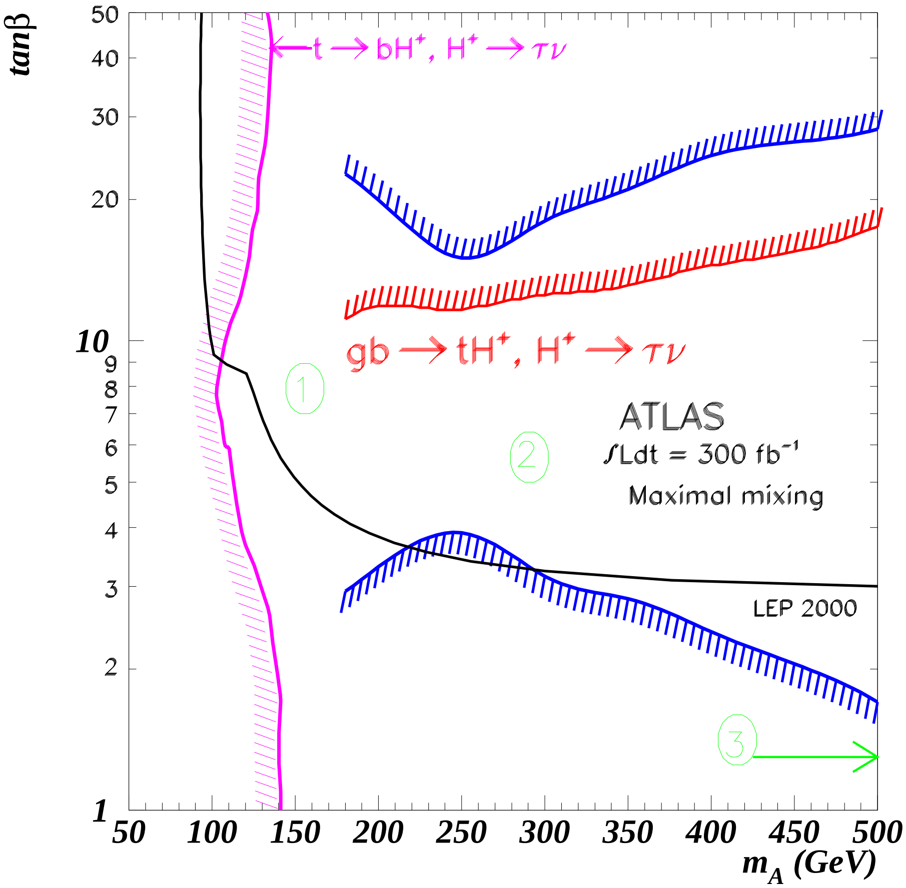
- For $m_{H^{\pm}} < m_t$:
  - $t \to bH^{\pm}$ where $gg, qq \to t\bar{t}$
  - Narrow Width Approximation: $gg, qq \to t\bar{t} \times t \to bH^{\pm}$
- For $m_{H^{\pm}} \sim m_t$: NWA does not work



  - Use instead: $gg \to tbH^{\pm}$ instead of $gg, qq \to t\bar{t}$ with $t \to bH^{\pm}$ $(gb \to tH^{\pm})$
  - $H^{\pm} \to \tau\nu$

$H^{\pm}$ in Transition Region

Also to cover the area around $m_A \sim 160$ GeV in the discovery contour



Determination of Ratios of Couplings

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- $\Gamma(H/A \to \tau^+\tau^-)$, $\Gamma(H/A \to b\bar{b})$, $\Gamma(H^+ \to \tau^+\nu_\tau) \propto \tan\beta^2$, $\Gamma(H^+ \to t\bar{b}) \propto \tan\beta^2 (\tan\beta \gtrsim 10)$
- But large corrections: $\boxed{h_b^{eff} = \frac{m_b(Q)}{1+\Delta m_b}}$

  Δm_b is a non-decoupling quantity:

  $$\boxed{\Delta m_b \simeq -\alpha_s \frac{\mu\, m_{\tilde{g}}}{M_{\tilde{b}}^2} \tan\beta}$$

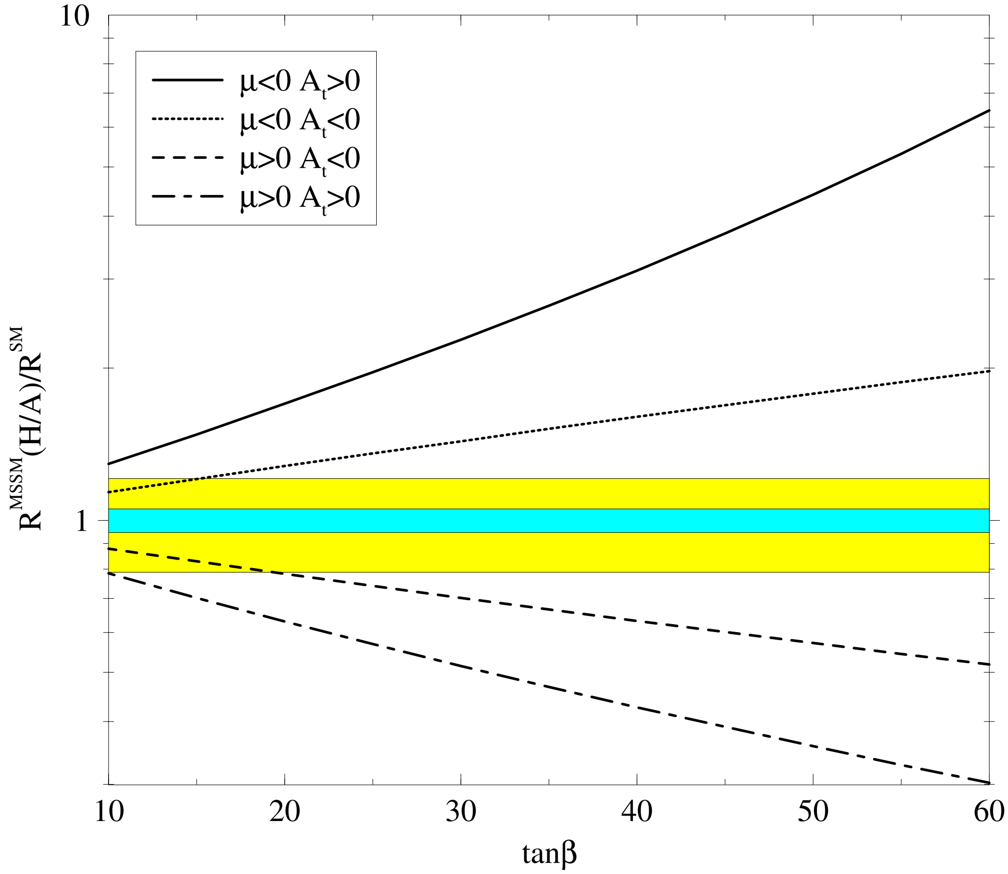
  $\Longrightarrow$ but different $\Delta m_b, \Delta m_\tau$ corrections!

$$R = \frac{BR(H/A \to b\bar{b})}{BR(H/A \to \tau^+\tau^-)} = \frac{BR(H^+ \to t\bar{b})}{BR(H^+ \to \tau^+\nu_\tau)}$$

$$R^{tree} = R^{SM} = \frac{3m_b^2(Q)}{m_\tau^2} \simeq 8.02(Q = 115 \text{ GeV})$$

$$\frac{R^{eff}}{R^{tree}} = \frac{\tan\beta_b^{eff}}{\tan\beta_\tau^{eff}}$$

Determination of Ratios of Couplings



- Prospects of the Determination of R in the $H^{\pm}$ sector by measuing the ratio of rates in $\tau\nu$ and tb channels:
  - Determination of sign of μ
  - constraints on SUSY models

Conclusions

- We propose to study the prospects for the determination of the top quark width at the LHC
- Such a measurement can be obtained from the measured single top production cross (in the W-gluon fusion and $W*$ channels) and from the measured $BR(t \to Wb)$ in $t\bar{t}$ events
- A measurement at the level of $\sim$ 10% would allow a test of the SM and other models including large extra dimensions with singlet neutrinos in the bulk (decay of the top-quark through a virtual charged Higgs)
- We also propose to study the discovery potential of $H^{\pm}$ in the transition region using $gg \to tbH^{\pm}$ with $H^{\pm} \to \tau\nu$: $m_{H^{\pm}} \sim m_t$.
- Using $H^{\pm} \to \tau\nu$ and $H^{\pm} \to tb$, we will study the prospects for the determination of $H^{\pm}$ couplings at large $\tan\beta$: to determine sign of μ and to constrain SUSY models