Decay of $B^{\pm} \to \tau^{\pm} +$ "missing momentum" and 2HDM(II)

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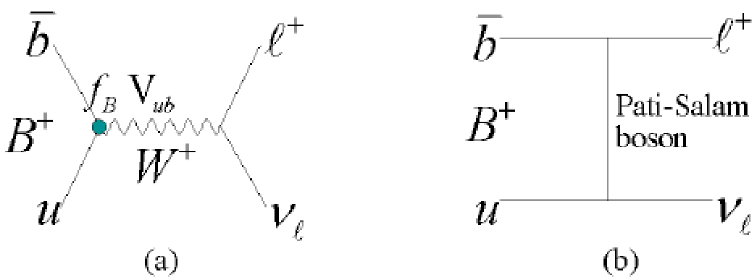
** Issues on $\Gamma(B^+ \to \tau^+ \nu)$

G Cvetic, CS Kim, YJ Kwon, PRD 93(2015) 013003

What Belle/BaBar had done:

$B^+ \to \tau^+ \nu_\tau$ the basics



$$\Gamma(B^+ \to \ell^+ \nu_\ell) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2$$ ←Need recalculate this

- very clean place to measure f_B (or V_{ub}?) and/or search for new physics (e.g. H^+, LQ)
- but, helicity-suppressed: $\Gamma(B^+ \to e^+\nu_e) \ll \Gamma(B^+ \to \mu^+\nu_\mu) \ll \Gamma(B^+ \to \tau^+\nu_\tau)$
- First evidence for $B^+ \to \tau^+\nu_\tau$ by Belle using hadronic tagging ("Full reconstruction") PRL 97, 251802 (2006)

Physics Issue

∵ Tau decay involves neutrinos, so m(nu) cannot be constrained.

➔ always more than 1 neutrinos

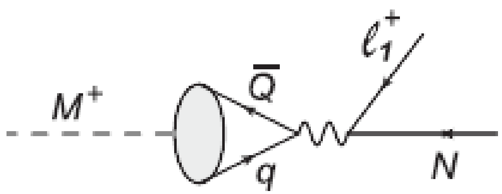
- When you see $B^+ \to \tau^+ + miss(E, \vec{P})$,

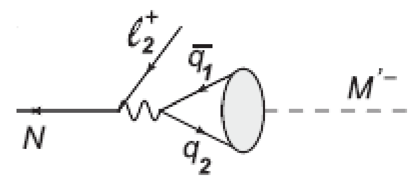
  Is the event $B^+ \to \tau^+ \nu$ or $B^+ \to \tau^+ N$?

  (where $N =$ massive sterile (Dirac or Majorana) particle)

Need to consider:

- Due to long lifetime of N, (and small P_N)



[

gone]

$$P_N = 1 - \exp(-L_D / L_N) \sim L_D / L_N$$
$$L_N = \gamma_N \beta_N \tau_N$$

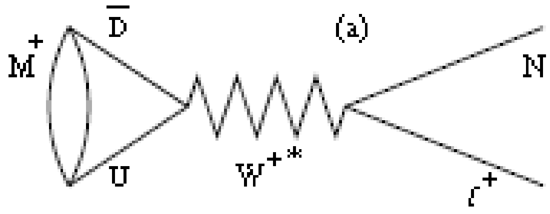
$$B^+ \to \tau^+ \nu_\tau \qquad\qquad M(\nu) = 0$$

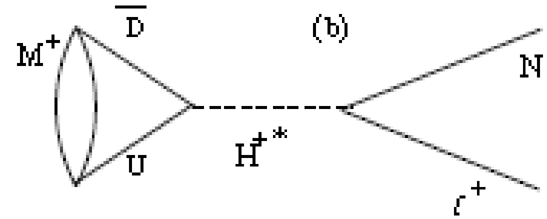
$$\Gamma_{\rm SM}(B^+ \to \nu_\tau \tau^+) = \frac{1}{8\pi} G_F^2 f_B^2 |V_{ub}|^2 \left(1 - \frac{M_\tau^2}{M_B^2}\right)^2 M_B M_\tau^2 \approx 4.69 \times 10^{-17}\ {\rm GeV}$$

$$\Gamma_{\rm 2HDM(II)}(B^+ \to \nu_\tau \tau^+) = \frac{1}{8\pi} G_F^2 f_B^2 |V_{ub}|^2 \left(1 - \frac{M_\tau^2}{M_B^2}\right)^2 M_B M_\tau^2 r_H^2 = r_H^2 \Gamma_{\rm SM}(B^+ \to \tau^+ \nu_\tau)$$

$$r_H = -1 + \frac{M_B^2}{M_H^2} \tan^2\beta$$

$M(N) \neq 0$





$$\Gamma_{\rm SM}(B^+ \to N\tau^+) = \frac{1}{8\pi} G_F^2 f_B^2 |V_{ub}|^2 |B_{\tau N}|^2 \lambda^{1/2}\left(1, \frac{M_N^2}{M_B^2}, \frac{M_\tau^2}{M_B^2}\right) \times \frac{1}{M_B}\left[(M_\tau^2 + M_N^2)(M_B^2 - M_N^2 - M_\tau^2) + 4M_N^2 M_\tau^2\right] ,$$

$$\Gamma_{\rm 2HDM(II)}(B^+ \to N\tau^+) = \frac{1}{8\pi} G_F^2 f_B^2 |V_{ub}|^2 |B_{\tau N}|^2 \lambda^{1/2}\left(1, \frac{M_N^2}{M_B^2}, \frac{M_\tau^2}{M_B^2}\right) \times \frac{1}{M_B}\left[(M_\tau^2 r_H^2 + M_N^2 l_H^2)(M_B^2 - M_N^2 - M_\tau^2) - 4 r_H l_H M_N^2 M_\tau^2\right]$$

$$r_H = -1 + \frac{M_B^2}{M_H^2}\tan^2\beta \qquad l_H = 1 + \frac{M_B^2}{M_H^2}$$

Need new numerical analysis (possibly 4 cases)

- 1 Within SM, $M(\nu)=0$ → $\Gamma_{\rm SM}(B^+ \to \nu_\tau \tau^+)$
- 2 With new physics (eg. 2HDM) with $M(\nu)=0$
  → $\Gamma_{\rm 2HDM(II)}(B^+ \to \nu_\tau \tau^+)$
- 3 Within SM with sterile N, $M(N)\neq 0$
  → $\Gamma_{\rm SM}(B^+ \to \nu_\tau \tau^+)$ + $\Gamma_{\rm SM}(B^+ \to N \tau^+)$
- 4 With new physics (eg. 2HDM) with $M(N)\neq 0$
  → $\Gamma_{\rm 2HDM(II)}(B^+ \to \nu_\tau \tau^+)$ + $\Gamma_{\rm 2HDM(II)}(B^+ \to N \tau^+)$

Br(B^+ → tau^+ + missing)_exp= (PDG average)= (1.14+-0.27) X 10^-4
Br(…)_SM= (CKMfitter)= (0.758 +- 0.080) X 10^-4

All parameter values from CKMfitter

TABLE I: Presently known upper bound estimates for $|B_{\ell N}|^2$ ($\ell = e, \mu, \tau$) for $M_N \approx 1, 3$ GeV; and the inverse canonical decay width $\overline{L}^{-1}$ (for $\gamma_N = 2$).

M_N [GeV]	$\|B_{eN}\|^2$	$\|B_{\mu N}\|^2$	$\|B_{\tau N}\|^2$	$\overline{L}_N^{-1} [m^{-1}]$
≈ 1.0	10^{-7}	10^{-7}	10^{-2}	115.
≈ 3.0	10^{-6}	10^{-4}	10^{-4}	$2.81 \cdot 10^4$

|B_tauN| from DELPHI, ZPC74(1997)57

$$BR\left(Z^0 \to \nu_m \overline{\nu}\right) = BR\left(Z^0 \to \nu \overline{\nu}\right) |U|^2 \left(1 - \frac{m_{\nu_m}^2}{m_{Z^0}{}^2}\right)^2 \times \left(1 + \frac{1}{2} \frac{m_{\nu_m}^2}{m_{Z^0}{}^2}\right),$$

Recent LHC (ATLAS, CMS) Results
for charged Higgs boson
NPB(Proc.Suppl.) 253(2014)171

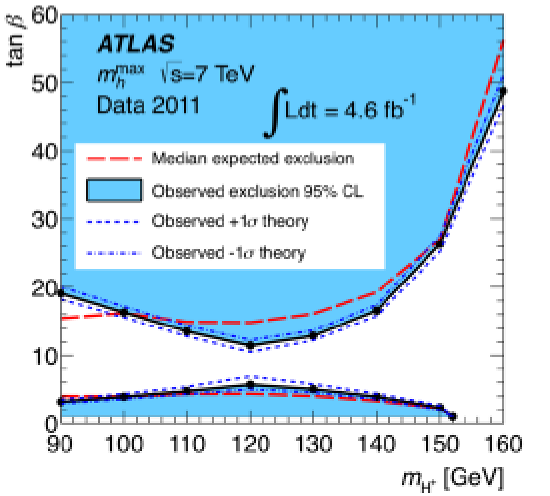


Figure 2: Combined 95% CL exclusion limits on tanβ as a function of m_{H^+} in the context of the MSSM m_h^{max} scenario [6].

Numerical analysis

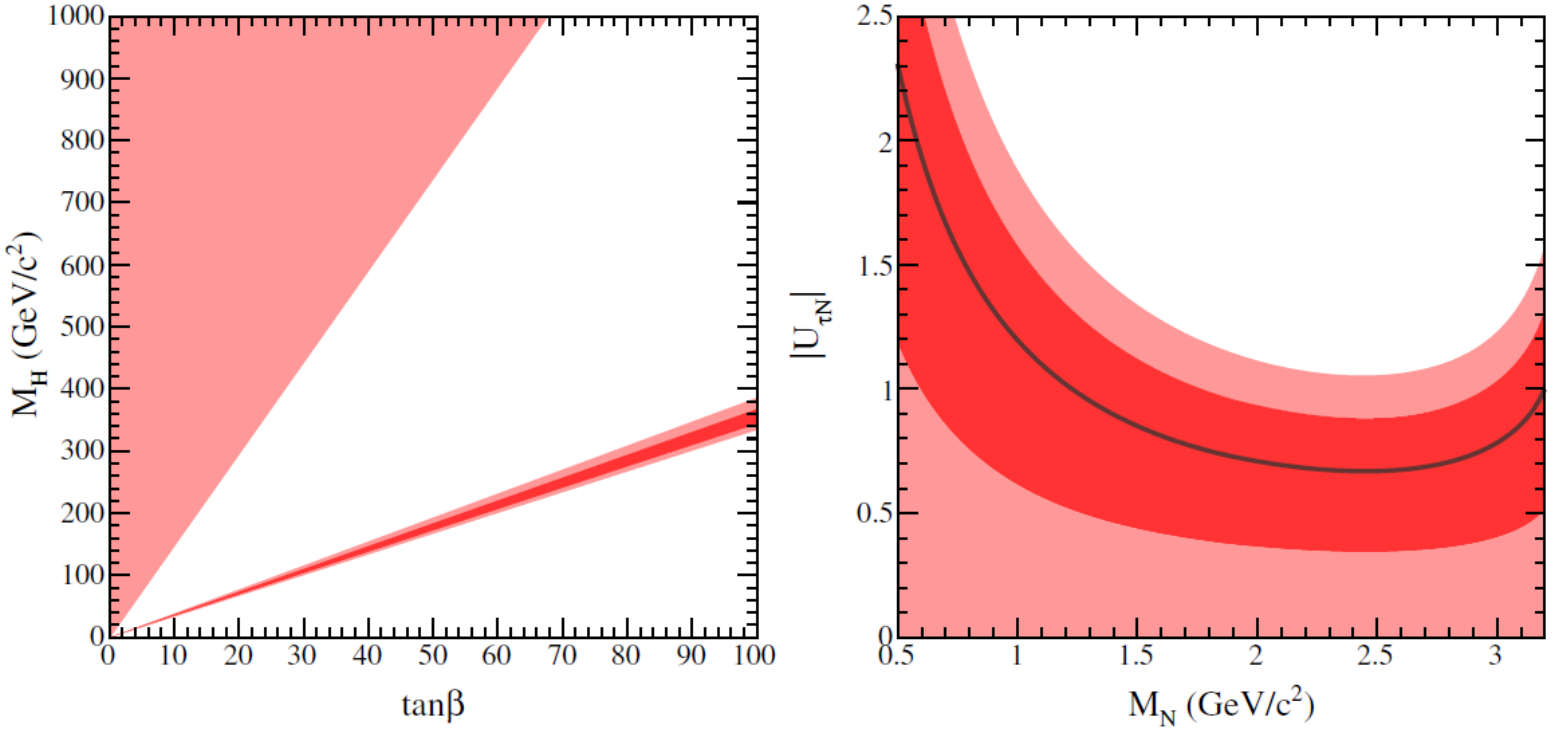


FIG. 1. The allowed regions determined from the measurement of $B^{\pm} \to \tau^{\pm}\nu$ in two cases: (left) the allowed regions in the parameter space of M_{H^+} vs $\tan\beta$ in 2HDM(II) assuming that the missing momenta are only from ν_τ of the SM; (right) the allowed regions in the parameter space of M_N vs $|U_{\tau N}|$ assuming no contributions from charged Higgs but allowing the possible contributions from heavy neutrino N. The dark- and pale-shaded areas (red online) correspond to $\pm 1\sigma$ and $\pm 2\sigma$ allowed regions, respectively.

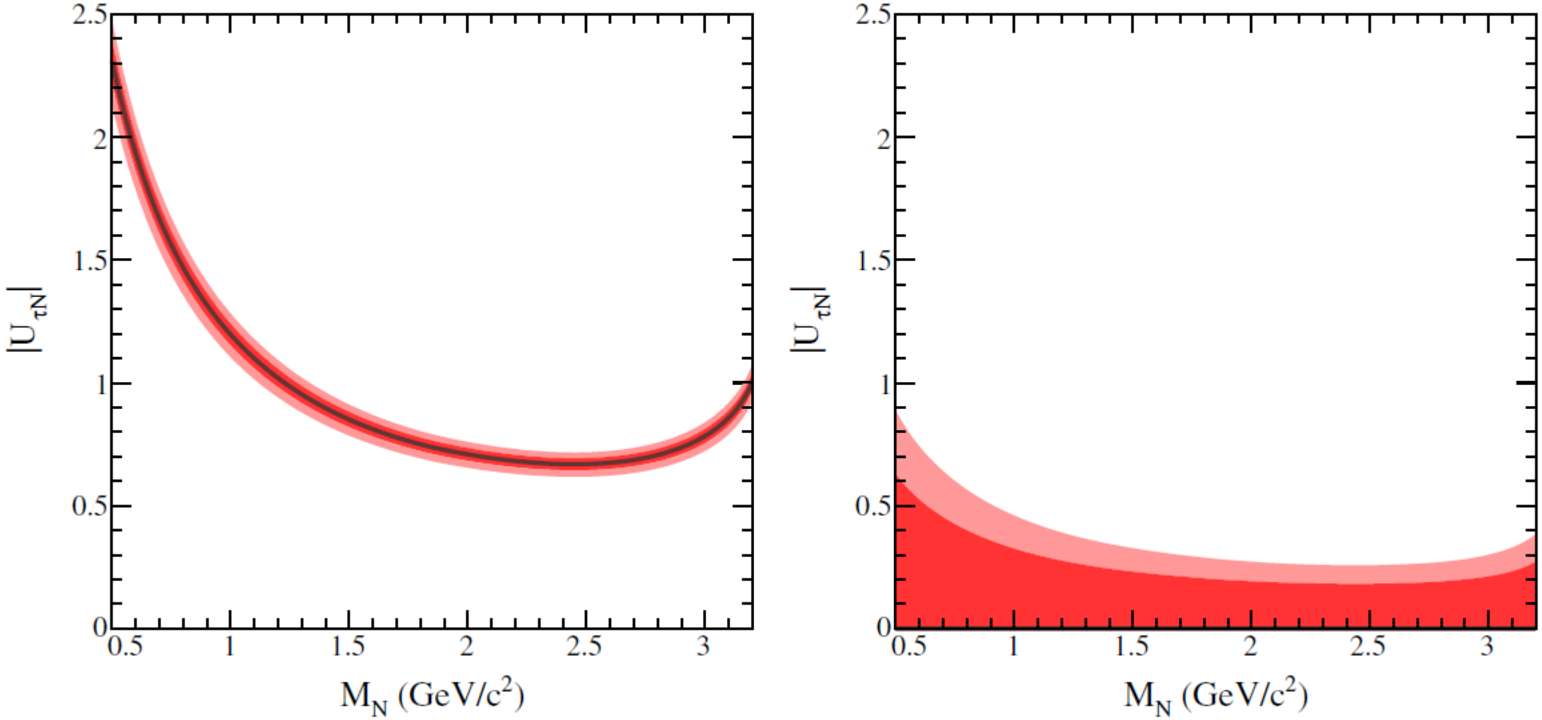


FIG. 2. The allowed regions in the parameter space of M_N and $|U_{\tau N}|$ assuming no contributions from the charged Higgs, where the $\pm 1\sigma$ and $\pm 2\sigma$ allowed regions are displayed by dark and pale shades (red online), respectively: (left) the central value of $\mathcal{B}(B^{\pm} \to \tau^{\pm}\nu)$ is taken as the current world average Eq. (1), while tenfold reduction of uncertainty is assumed; (right) the central value is taken to be the value predicted by the CKM unitarity constraint, also assuming tenfold reduction of experimental uncertainty. In all cases, the comparison is made to the value determined from the CKM unitarity fitting Eq. (2).

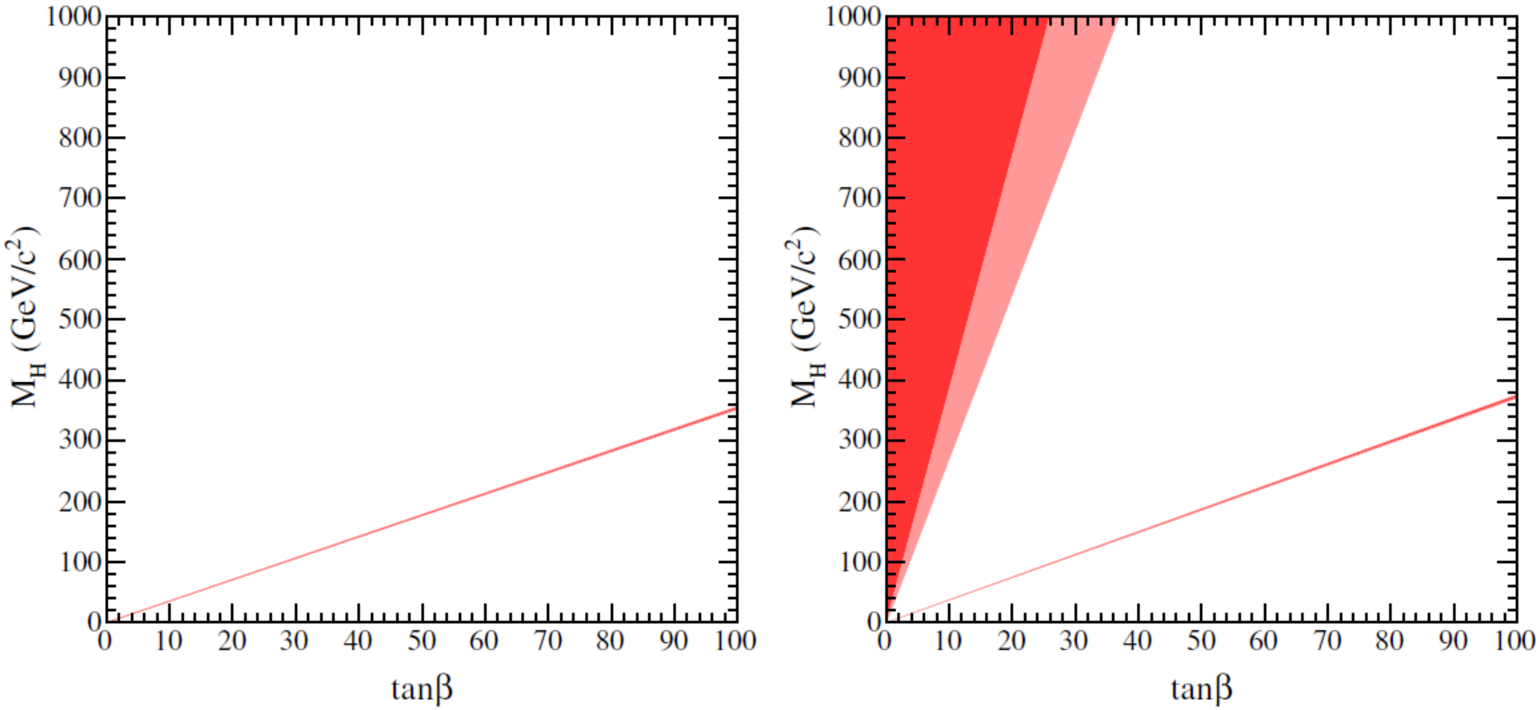


FIG. 3. The allowed regions in the parameter space of M_{H^+} vs $\tan\beta$ in 2HDM (type II), assuming no contributions from heavy neutral particle N, where the $\pm 1\sigma$ and $\pm 2\sigma$ allowed regions are displayed by dark and pale shades (red online), respectively: (left) the central value of $\mathcal{B}(B^\pm \to \tau^\pm \nu)$ is taken from the current world average, while tenfold reduction of uncertainty is assumed; (right) the central value is taken to be the value predicted by the CKM unitarity constraint, also assuming tenfold reduction of experimental uncertainty. In both cases, the comparison is made to the value determined from the CKM unitarity constraints Eq. (2).

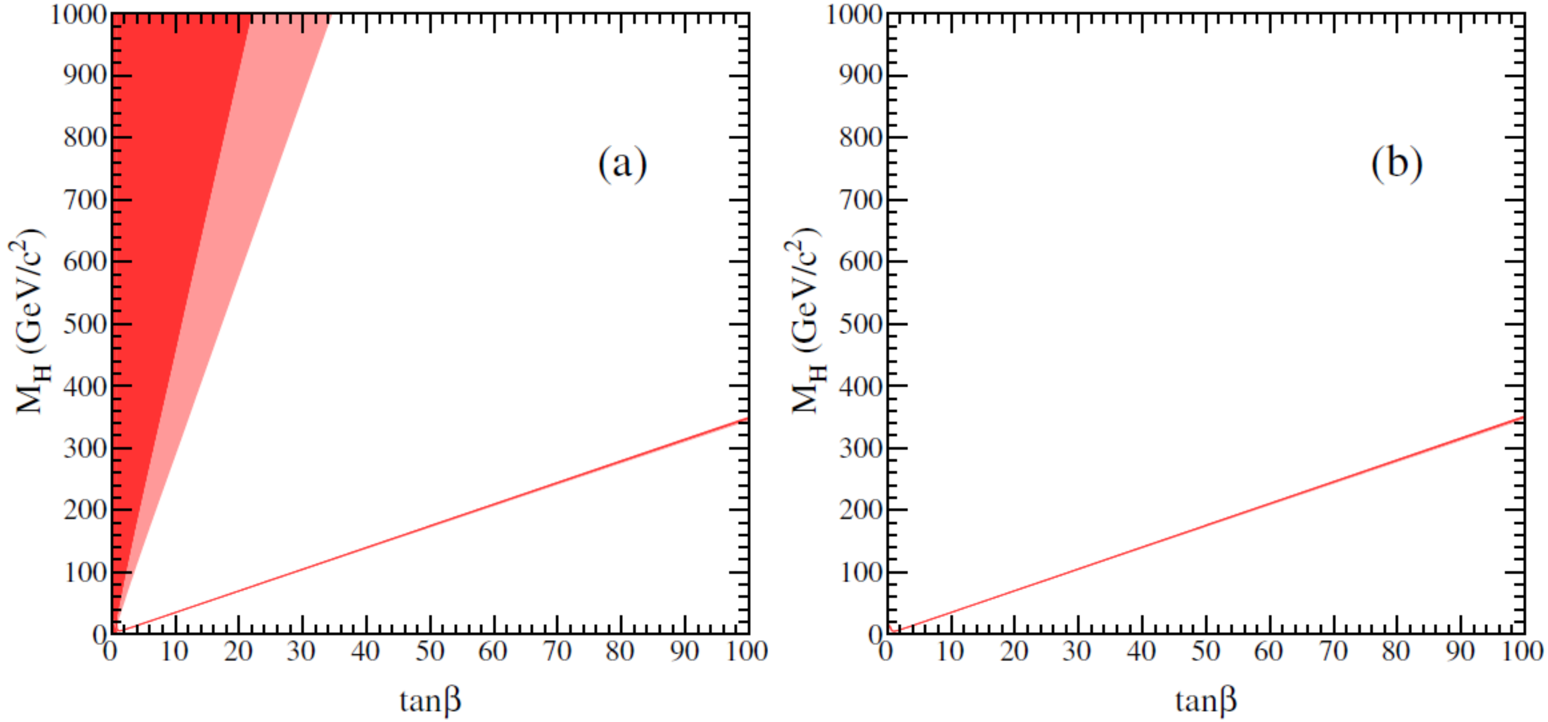


FIG. 4. The allowed regions under the assumption that both H^+ and N contribute to the measured value of $B^\pm \to \tau^\pm \nu$, based on the decay rates of Eqs. (5) and (8b). (a) The allowed region in the parameter space of M_{H^+} and $\tan\beta$ when $M_N = 1.0$ GeV$/c^2$ and $|U_{\tau N}| = 0.6$. (b) The allowed region when $M_N = 1.0$ GeV$/c^2$ and $|U_{\tau N}| = 0.5$. (c) The allowed region in the parameter space of $|U_{\tau N}|$ and M_N when $M_{H^+} = 200$ GeV$/c^2$ and $\tan\beta = 56.5$. (d) The allowed region when $M_{H^+} = 200$ GeV$/c^2$ and $\tan\beta = 55$.

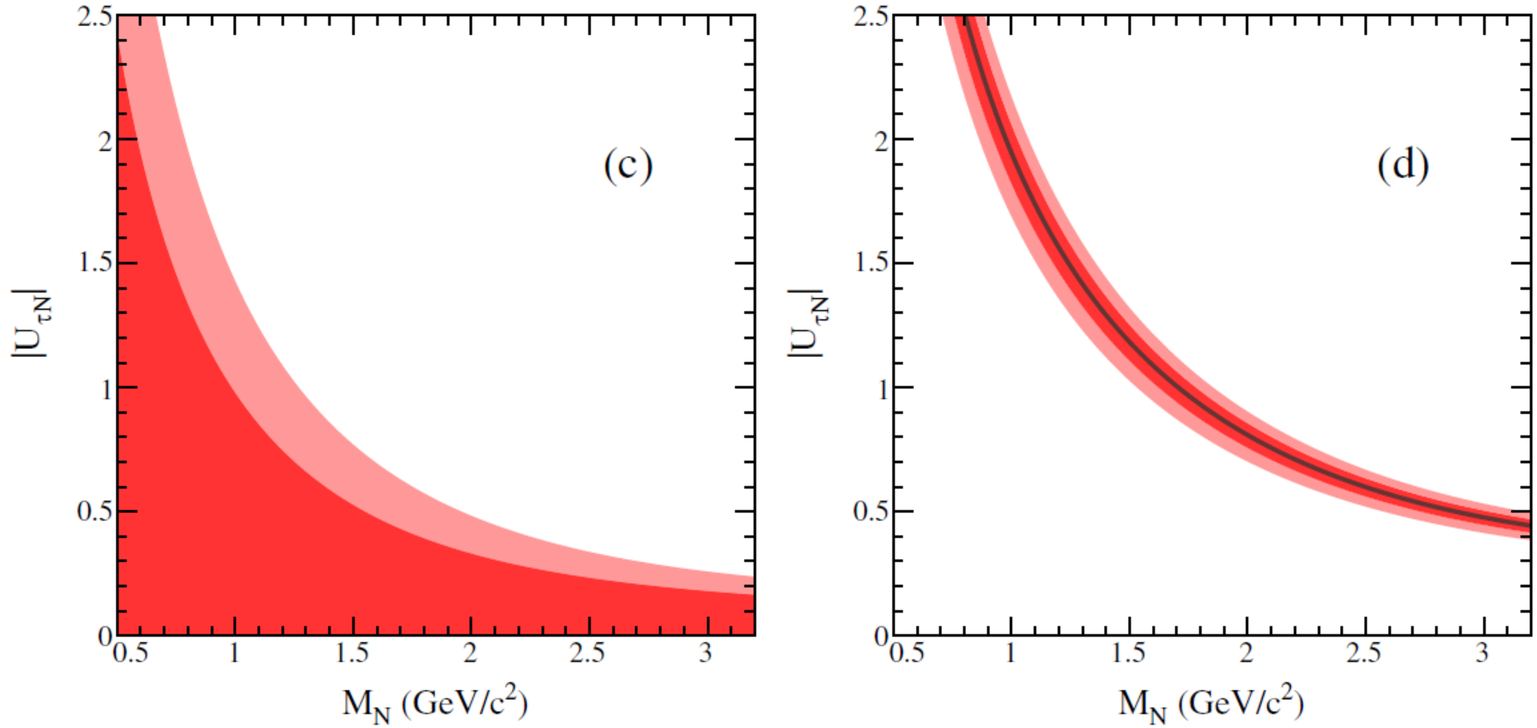


FIG. 4. The allowed regions under the assumption that both H^+ and N contribute to the measured value of $B^\pm \to \tau^\pm \nu$, based on the decay rates of Eqs. (5) and (8b). (a) The allowed region in the parameter space of M_{H^+} and $\tan\beta$ when $M_N = 1.0\ \mathrm{GeV}/c^2$ and $|U_{\tau N}| = 0.6$. (b) The allowed region when $M_N = 1.0\ \mathrm{GeV}/c^2$ and $|U_{\tau N}| = 0.5$. (c) The allowed region in the parameter space of $|U_{\tau N}|$ and M_N when $M_{H^+} = 200\ \mathrm{GeV}/c^2$ and $\tan\beta = 56.5$. (d) The allowed region when $M_{H^+} = 200\ \mathrm{GeV}/c^2$ and $\tan\beta = 55$.