Effect of $H^{\pm}$ on $B^{\pm} \to \tau^{\pm}\nu_{\tau}$ and $D_s^{\pm} \to \mu^{\pm}\nu_{\mu}$

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Abstract

The recent observation of the purely leptonic decay $B^{\pm} \to \tau^{\pm}\nu_{\tau}$ at the B factories permits a sizeable contribution from a charged Higgs boson ($H^{\pm}$). Such a $H^{\pm}$ would also contribute to the decays $D_s^{\pm} \to \mu^{\pm}\nu_{\mu}$ and $D_s^{\pm} \to \tau^{\pm}\nu_{\tau}$, which are being measured with increasing precision at CLEO-c. We show that the branching ratios of $D_s^{\pm} \to \mu^{\pm}\nu_{\mu}$ and $D_s^{\pm} \to \tau^{\pm}\nu_{\tau}$ could be suppressed by up to 10% from the Standard Model prediction, which is larger than the anticipated precision in the measurements of these decays at forthcoming BES-III.

A.G. Akeroyd, Prog.Theo.Phys.111 (2004) 295 (hep-ph/0308260)
A.G. Akeroyd and Chuan Hung Chen, hep-ph/0701078 (to appear in PRD)

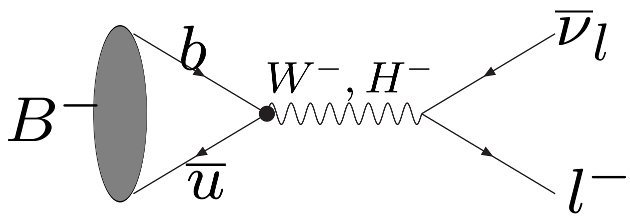
Outline

- Purely leptonic decays $B^{\pm} \to l^{\pm}\nu_l$
- First observation of $B^{\pm} \to \tau^{\pm}\nu_\tau$ at BELLE (April 2006)
- Possible large contribution from $H^{\pm}$
- Effect of $H^{\pm}$ on $D_s^{\pm} \to \mu^{\pm}\nu_\mu$ and $D_s^{\pm} \to \tau^{\pm}\nu_\tau$
- Prospects for probing $H^{\pm}$ at CLEO-c and BES-III

The decays $B^{\pm} \to l^{\pm}\nu_l$

Analogies of $\pi \to l\nu_l$ and $K^{\pm} \to l\nu_l$

Proceed via annihilation of $B^{\pm}$ into $W^{\pm}$ (SM) and $H^{\pm}$ (2HDM)



Search only possible at e^+e^- colliders

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

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

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

$$Y = \tan^2\beta(m_b m_l/m_{H^{\pm}}^2)$$

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 $r_H = 1$

Origin of m_l dependence

Angular momentum conservation requires that both $l^{\pm}$ and ν have the same helicities, $l_R^-\overline{\nu}_R$ and $l_L^+\nu_L$

- W^- mediated diagram produces $l_L^-\overline{\nu}_R$
  $\rightarrow m_l$ helicity suppression from $l_L^- \rightarrow l_R^-$

- H^- contribution produces $l_R^-\overline{\nu}_R$.
  $\rightarrow m_l$ suppression comes from Yukawa coupling

Branching Ratios in Standard Model

$$BR(B^+ \to \tau^+ \nu_\tau) : BR(B^+ \to \mu^+ \nu_\mu) : BR(B^+ \to e^+ \nu_e)$$

$$0.8 m_\tau^2 : m_\mu^2 : m_e^2$$

Decay	SM Prediction	Limits	Exp
$B^+ \to e^+ \nu_e$	9.2×10^{-12}	$\leq 1.5 \times 10^{-5}$	CLEO (1995)
$B^+ \to \mu^+ \nu_\mu$	3.9×10^{-7}	$\leq 2.1 \times 10^{-5}$	CLEO (1995)
$B^+ \to \tau^+ \nu_\tau$	1.6×10^{-4}	$\leq 5.7 \times 10^{-4}$	LEP (1997)

Sizeable error in SM prediction ($\sim 25\%$) from V_{ub} and f_B

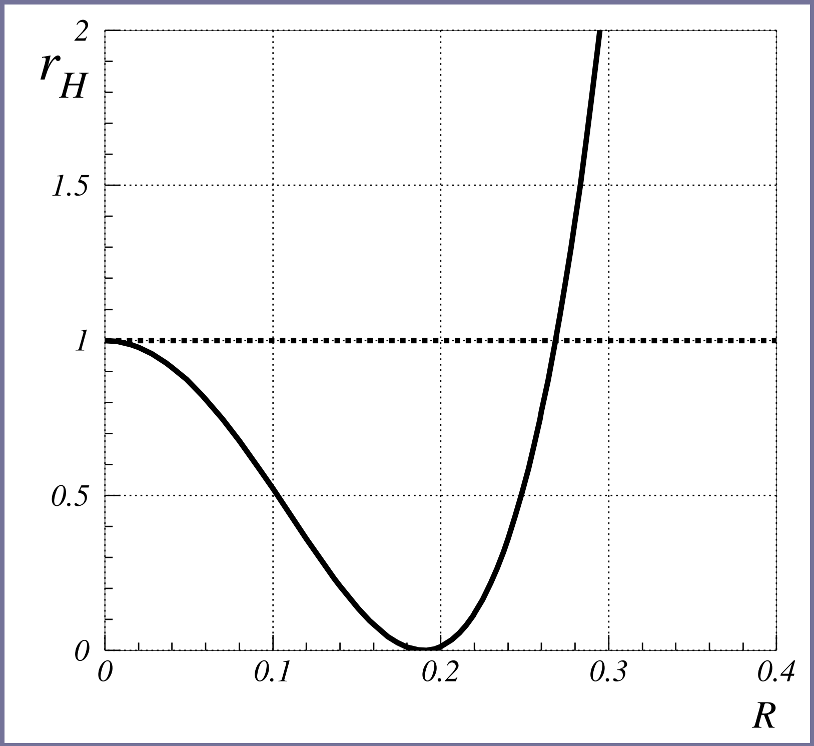
Effect of $H^{\pm}$

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

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

- Destructive interference
- Sensitivity to $R = \frac{\tan\beta}{m_{H^{\pm}}}$
- R very important parameter in 2HDM and MSSM
- $\tan\beta$ and $m_{H^{\pm}}$ completely define tree-level MSSM Higgs potential

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



Two solutions for $r_H = 1$ i) $R = 0$ and ii) $R = 0.27$

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

First observation of purely leptonic $B^{\pm}$ decay by BELLE:

K.Ikado et al, Phys.Rev.Lett.97:251802 (2006) (hep-ex/0604018); 450×10^{6} $B^{\pm}$s

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

In agreement with SM expectation $(1.6 \pm 0.4 \times 10^{-4})$

but does not preclude *large contribution* from $H^{\pm}$

(BABAR: $\text{BR}(B^{\pm} \to \tau^{\pm}\nu_{\tau}) < 1.8 \times 10^{-4}$; $300 \times 10^{6} B^{\pm}$s)

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

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

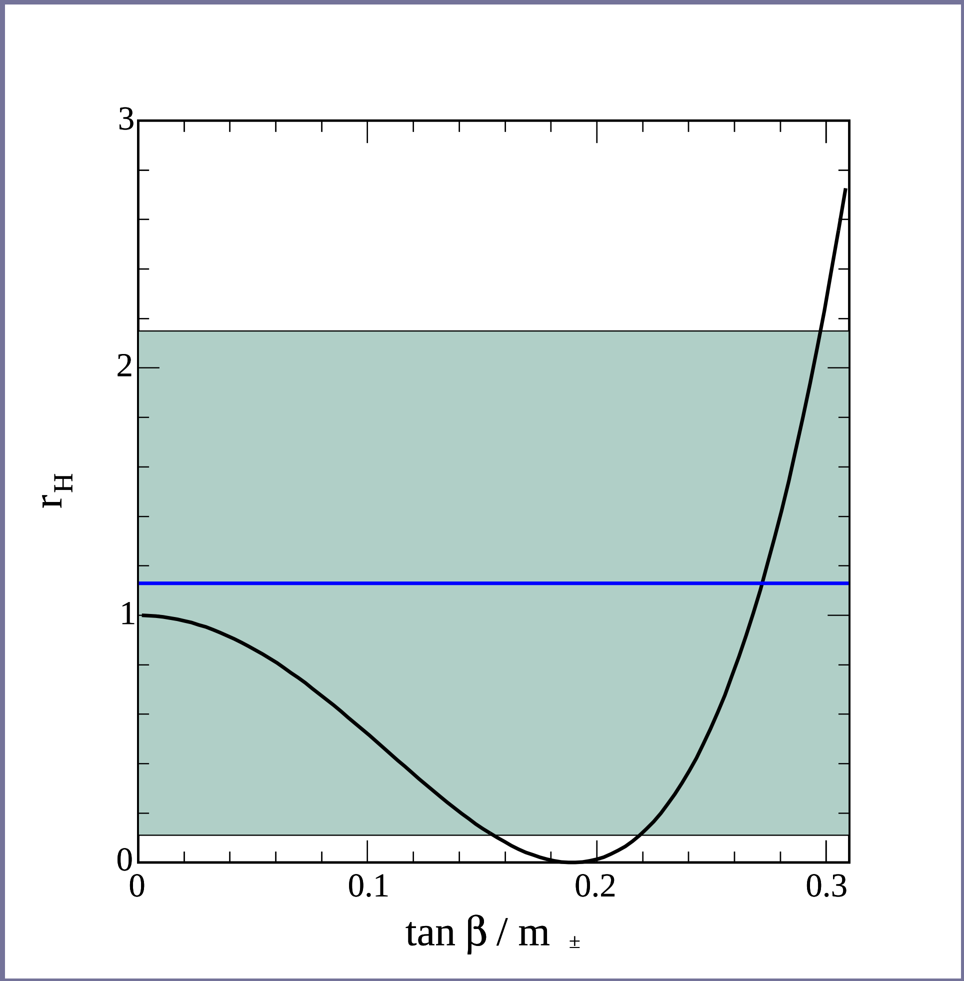
$\to$ $|V_{ub}|$ and f_B

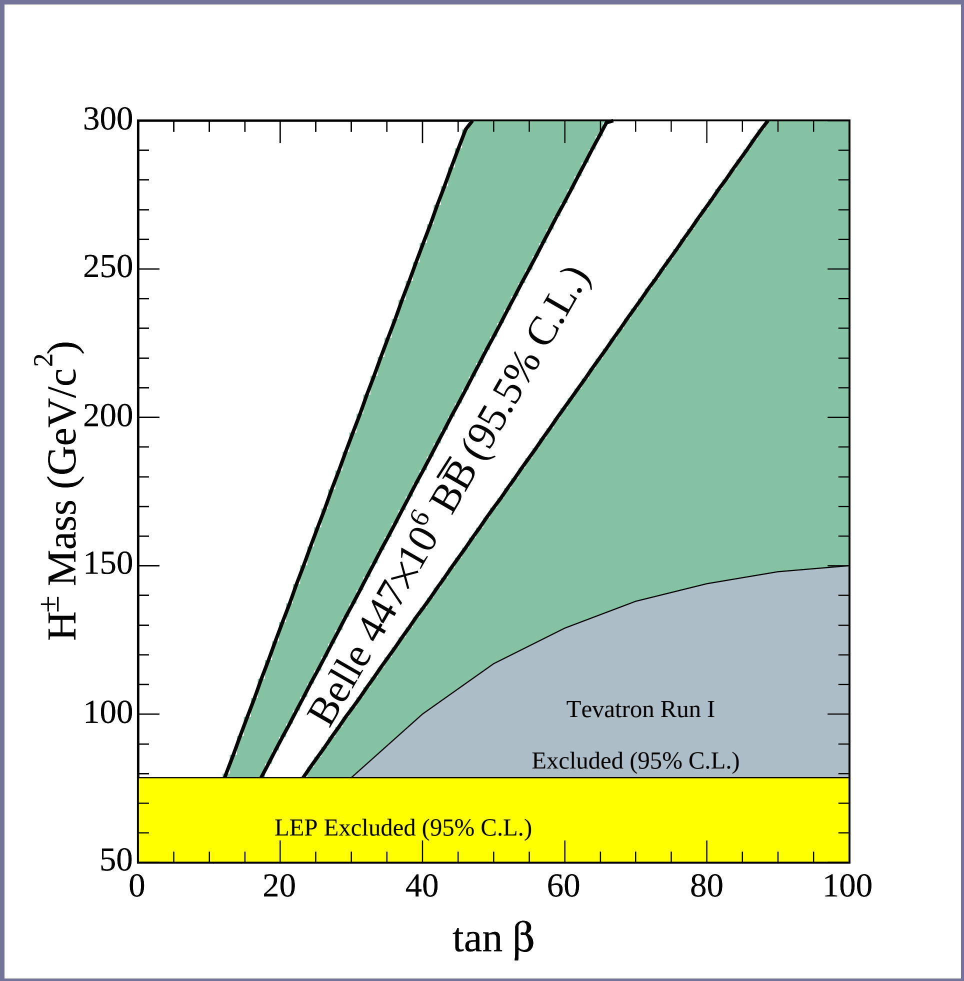
BELLE take:

- $|V_{ub}| = (4.39 \pm 0.33) \times 10^{-3}$ (Experiment)
- $f_B = 0.216 \pm 0.022$ GeV (Unquenched Lattice QCD)

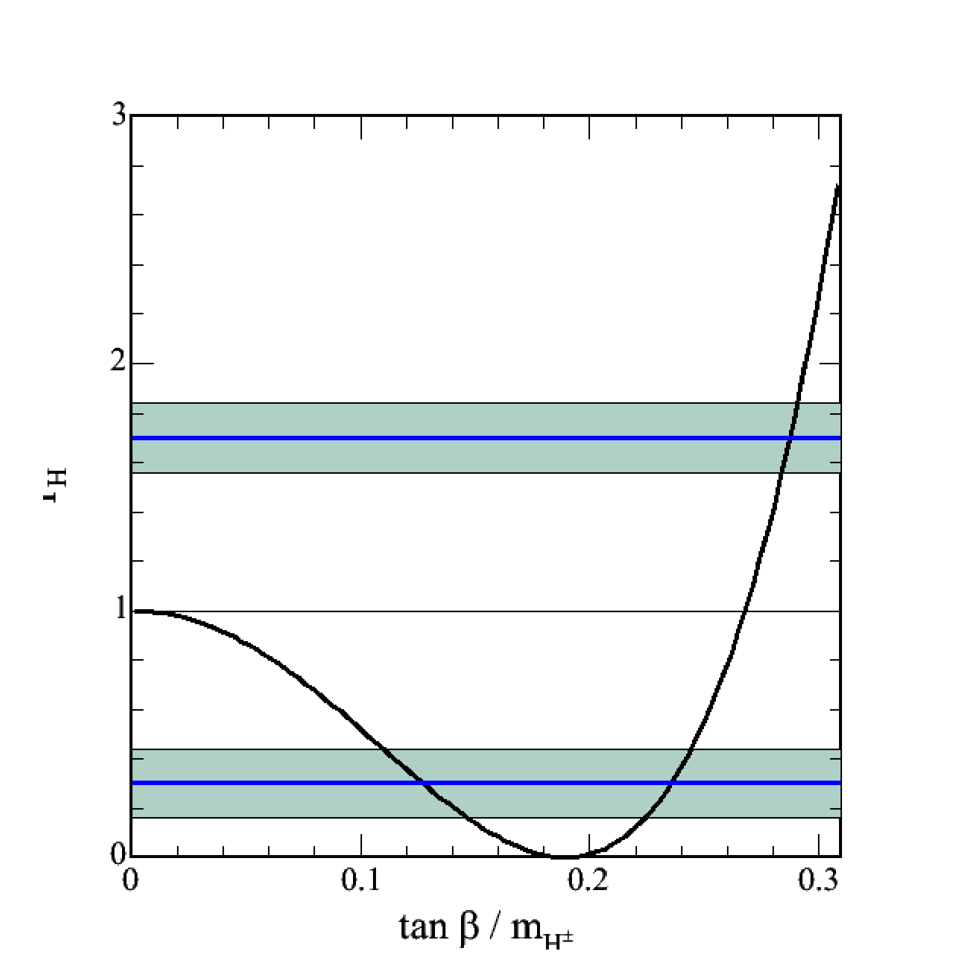
$$r_H = 1.13 \pm 0.51$$

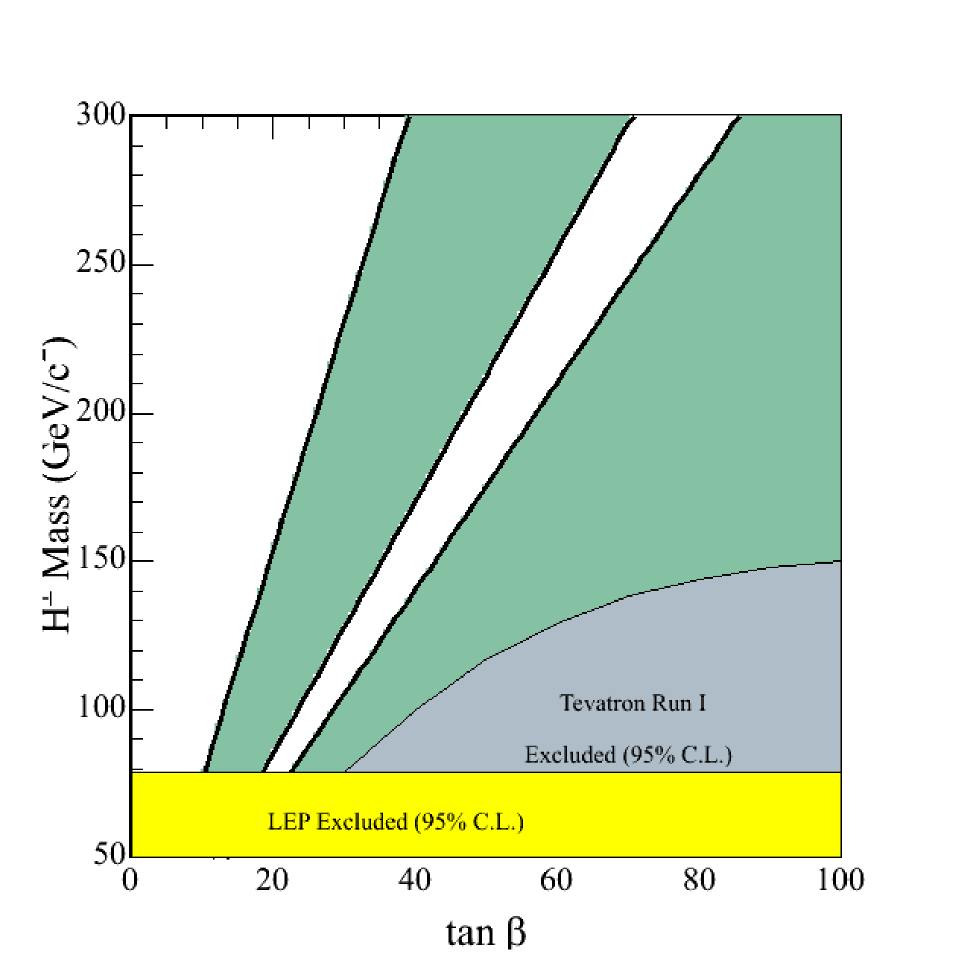
Constraint on r_H and plane $[\tan\beta, m_{H^\pm}]$ (0.414 ab^{-1})



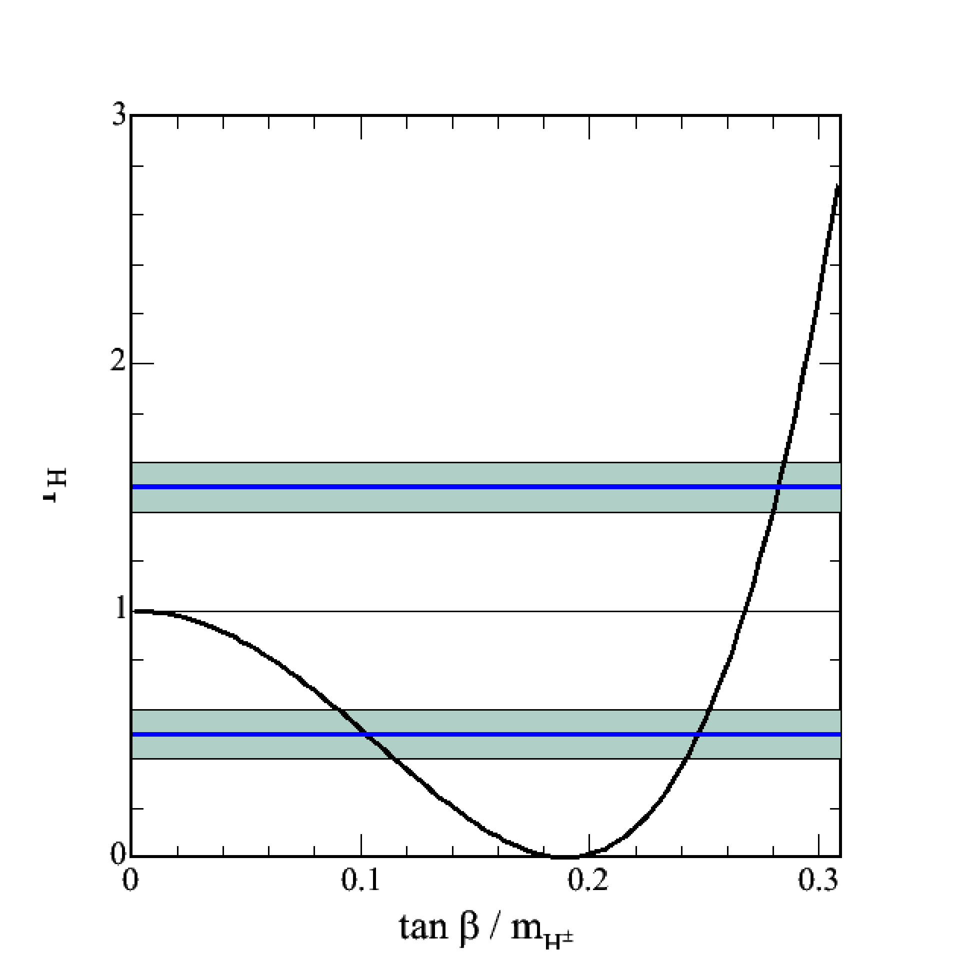


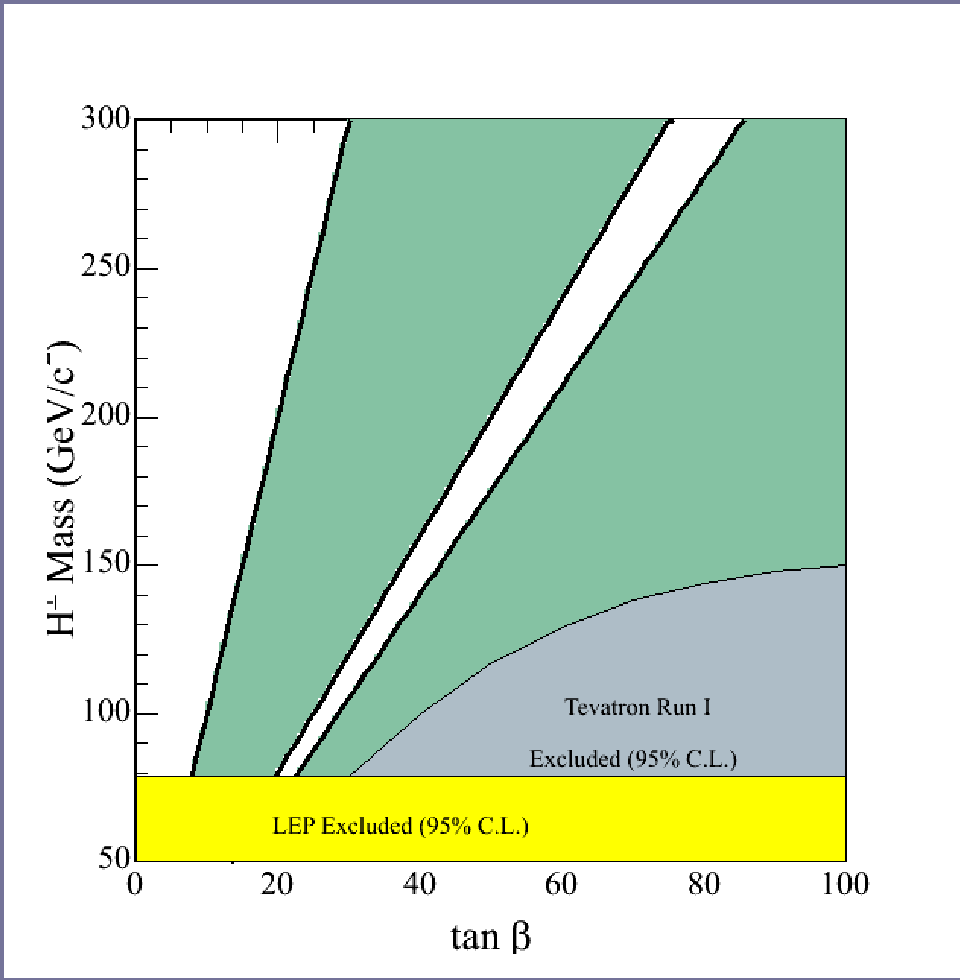
Prospects with 5 ab^{-1} (2012?)



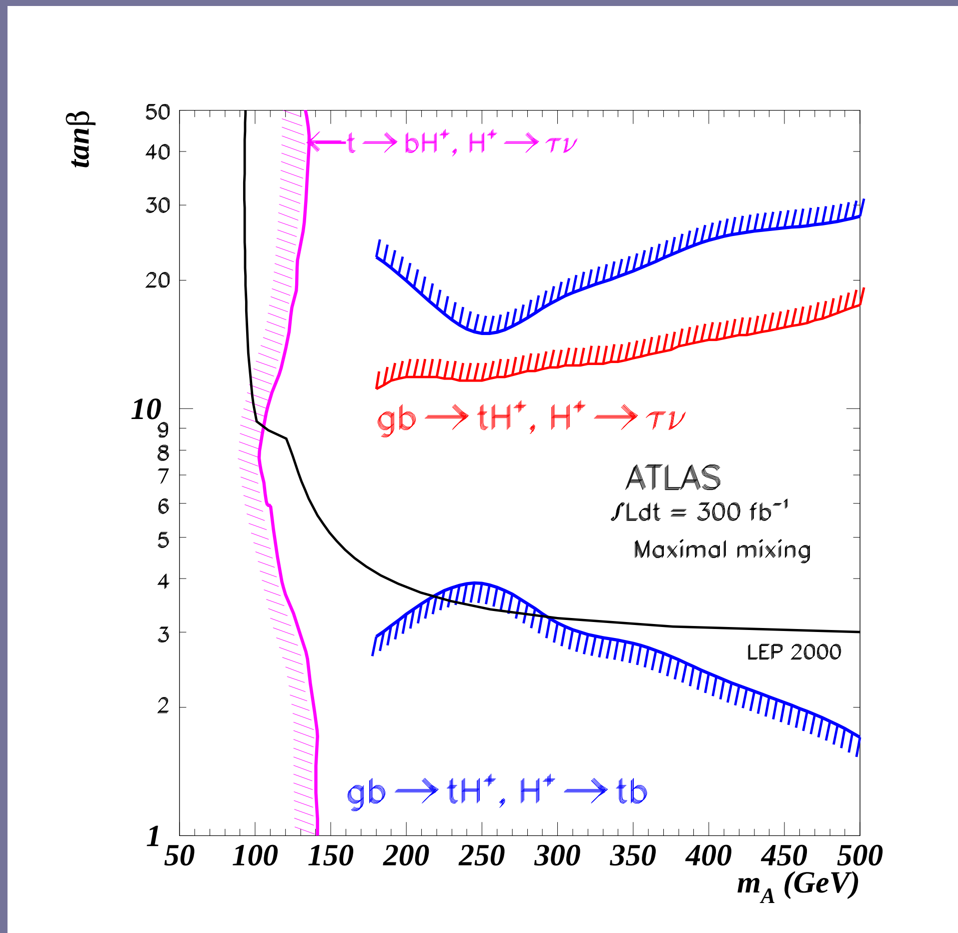


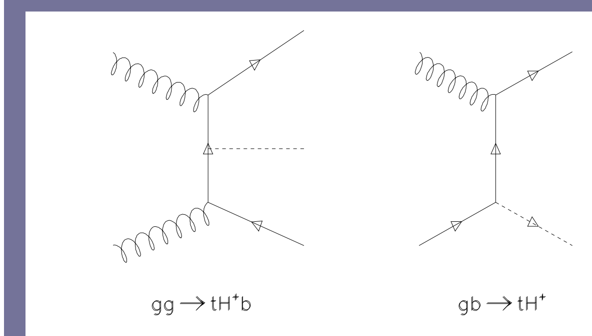
Prospects with 50 ab^{-1} (2018?)





LHC probe of [$\tan\beta, m_{H^\pm}$] via direct $H^\pm$ production





Will easily cover region $R \sim 0.27$

Summary

- BELLE observed $B^{\pm} \to \tau^{\pm}\nu_{\tau}$ with roughly SM rate
- Large contribution from $H^{\pm}$ still possible

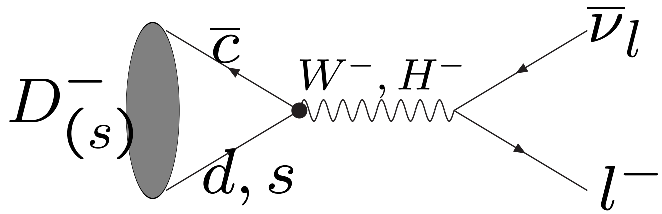
$(R = \tan\beta/m_{H^{\pm}} \sim 0.27)$

- LHC will easily discover such a $H^{\pm}$

Any other observables sensitive to $H^{\pm}$ with $R \sim 0.27$?

$H^{\pm}$ effect on the decays $D_s^{\pm} \to \mu^{\pm}\nu, \tau^{\pm}\nu$

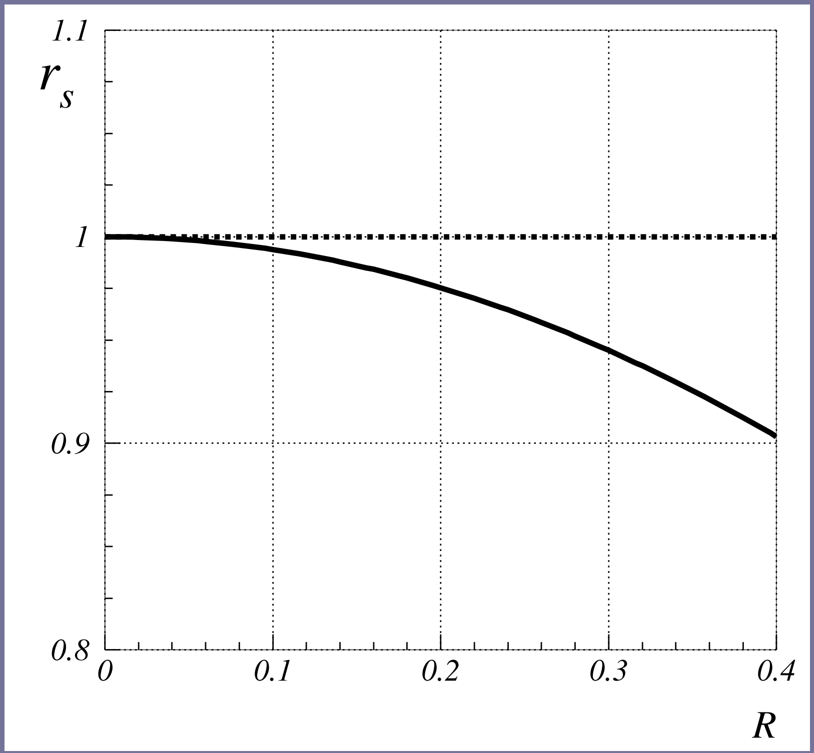
$H^{\pm}$ would also contribute to leptonic charm decays:



$$\Gamma(D^{\pm}_{(s)} \to l^{\pm}\nu_l) = \frac{G_F^2 m_{D_{(s)}} m_l^2 f_{D_{(s)}}^2}{8\pi} |V_{cd(cs)}|^2 \left(1 - \frac{m_l^2}{m_{D_{(s)}}^2}\right)^2 \times r_{(s)}$$

$$r_{(s)} = [1 - m_{D_q}^2 R^2 (\frac{m_q}{m_c + m_q})]^2$$

Scaling factor r_s as a function of R for $m_s/m_c = 0.08$



Perturbation to SM rate - observable ?

Status of leptonic decays of $D_s^\pm$ before 2000

BR($D_s^\pm \to \mu^\pm\nu, \tau^\pm\nu$) much larger than BR($B^\pm \to \tau^\pm\nu$)
Main error from f_{D_s} (V_{cs} well measured)

Decay	SM Prediction	Measurement	Exp
$D_s^\pm \to \mu^+\nu_\mu$	5.2×10^{-3}	$5.3 \pm 0.9 \pm 1.2 \times 10^{-3}$	various (> 1995)
$D_s^\pm \to \tau^+\nu_\tau$	5.1×10^{-2}	$6.1 \pm 1.0 \pm 0.2 \pm 1.3 \times 10^{-2}$	LEP (1997)

- CLEO-c (2003) and BES-III (2008) offer improved precision
- Observing small perturbations to SM rate from $H^\pm$ might not hopeless

CLEO-c

- Used to be a B factory $\sqrt{s} = 10.6$ GeV
- In 2003 changed to $\sqrt{s} = 3.8 \to 4.2$ GeV
- Charm physics facility
- Will operate until April 2008
- Expects of order $10^{5-6} D_s^{\pm}$

Beijing Electron Positron Collider (BEPC/BES-III)

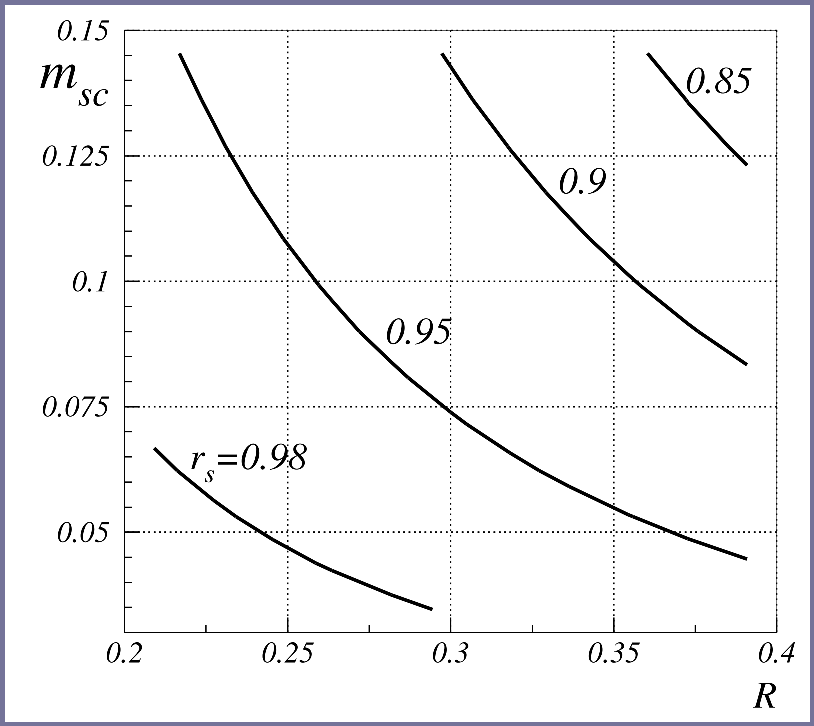
- Existing facility upgraded
- Due to start in 2008
- $\sqrt{s} = 3.8 \rightarrow 4.2$ GeV
- > 4 years of operation
- Expects up to 20 times CLEO-c number $D_s^{\pm}$

Leptonic decays at CLEO-c

Decay	SM BR ($\pm$30%)	Current Exp BR	CLEO-c error	BES-III error
$D^{\pm} \to e^{\pm}\nu$	8.24×10^{-9}	$< 2.4 \times 10^{-5}$		
$D^{\pm} \to \mu^{\pm}\nu$	3.50×10^{-4}	$4.40 \pm 0.66^{+0.09}_{-0.12} \times 10^{-4}$	$\sim 10\%$	$\sim 2\%$
$D^{\pm} \to \tau^{\pm}\nu$	9.25×10^{-4}	$< 2.1 \times 10^{-3}$		
$D_s^{\pm} \to e^{\pm}\nu$	1.23×10^{-7}	$< 3.1 \times 10^{-4}$		
$D_s^{\pm} \to \mu^{\pm}\nu$	5.22×10^{-3}	$6.57 \pm 0.9 \pm 0.28 \times 10^{-3}$	$\sim 10\%$	$\sim 2\%$
$D_s^{\pm} \to \tau^{\pm}\nu$	5.09×10^{-2}	6.5 ± 0.8	$\sim 10\%$	$\sim 1.5\%$

Precise measurements expected within 5 years!

Contours of r_s in the plane $[R, m_{sc}]$



Deviation from SM rate larger than expected precision from BES-III

Impact of $H^\pm$ on measurements of BR($D_s^\pm \to \mu^\pm\nu, \tau^\pm\nu$)

- Lowers BR($D_s^\pm \to \mu^\pm\nu, \tau^\pm\nu$) by up to 10%
- Larger then anticipated BES-III error
- Comparable to Lattice QCD error in calculation of f_{D_s}
- Deceptively smaller measured value of decay constant f_{D_s}
- If $H^\pm$ found at LHC, $r_s < 1$ should be included when comparing Lattice calculation of f_{D_s} to experimental value for f_{D_s}

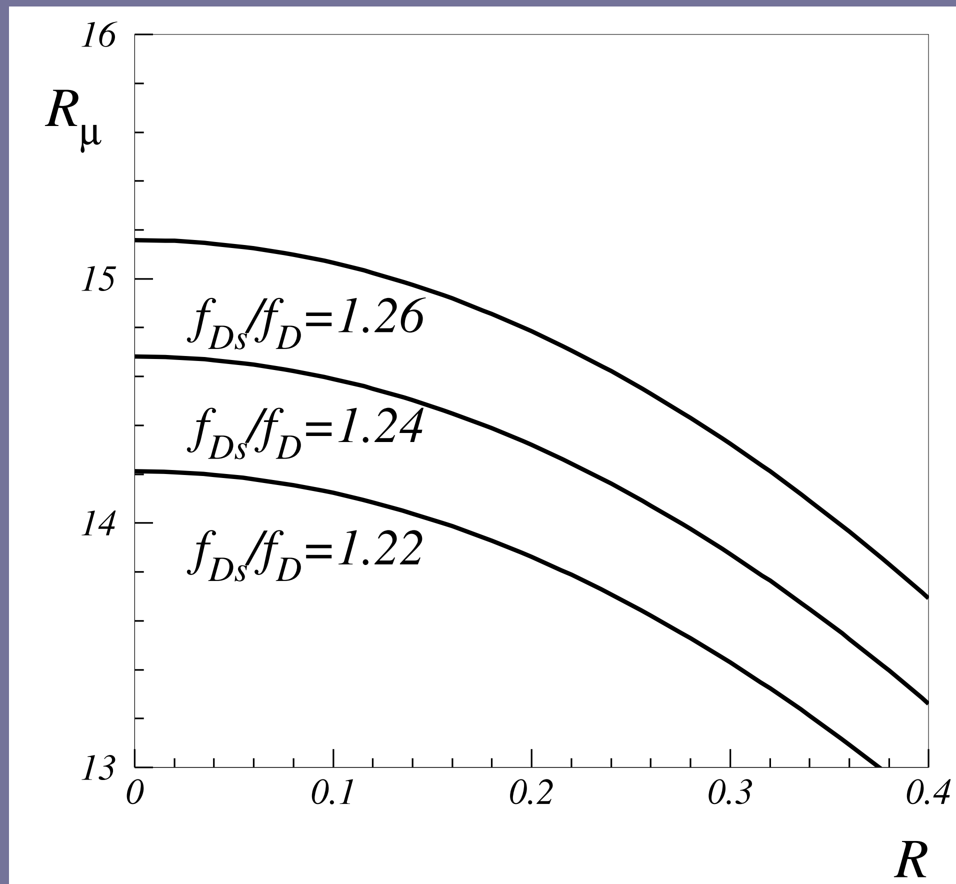
Probing $H^{\pm}$ at CLEO-c and BES-III

Observable most sensitive to $H^{\pm}$:

$$\mathcal{R}_\mu = \frac{BR(D_s^{\pm}\to\mu^{\pm}\nu_\mu)}{BR(D^{\pm}\to\mu^{\pm}\nu_\mu)} \sim r_s(\frac{f_{D_s}}{f_D})^2$$

- $H^{\pm}$ effect on BR$(D^{\pm} \to \mu^{\pm}\nu_\mu)$ negligible
- Lattice error for $f_{D_s}^2/f_D^2$ ($\sim$ 12%) less than $f_{D_s}^2$ ($\sim$ 30%)
- CLEO-c currently measures $\mathcal{R}_\mu$ with $\sim$ 20% error
- BES-III expects precise measurement of $\mathcal{R}_\mu$
- Could favour or disfavour $H^{\pm}$ with $R \sim 0.27$

$\mathcal{R}_\mu$ as a function of R



Conclusions

- $H^\pm$ could be contributing sizeably to $B^\pm \to \tau^\pm \nu_\tau$
- Such a $H^\pm$ would affect $D_s^\pm \to \mu^\pm \nu_\mu, \tau^\pm \nu_\tau$
- Suppression of BR($D_s^\pm \to \mu^\pm \nu_\mu, \tau^\pm \nu_\tau$) by up to 10%
- Precise measurements possible at CLEO-c and BES-III
- $H^\pm$ would cause deceptively smaller measured value of f_{D_s}
- $\mathcal{R}_\mu = \frac{BR(D_s^\pm \to \mu^\pm \nu_\mu)}{BR(D^\pm \to \mu^\pm \nu_\mu)}$ may favour or disfavour $H^\pm$