$B \to \tau \nu_\tau$ and a hint for H+

Flavor Physics at the LHC ERA
(workshop 2005-7,5 meetings,
YellowReport in prep.)

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Workshop 16.05.2007

Flavor Physics

Rare processes…

- Here inclusive and exclusive B to tau decays – data, SM and 2HDM
- W+ contra H+ :

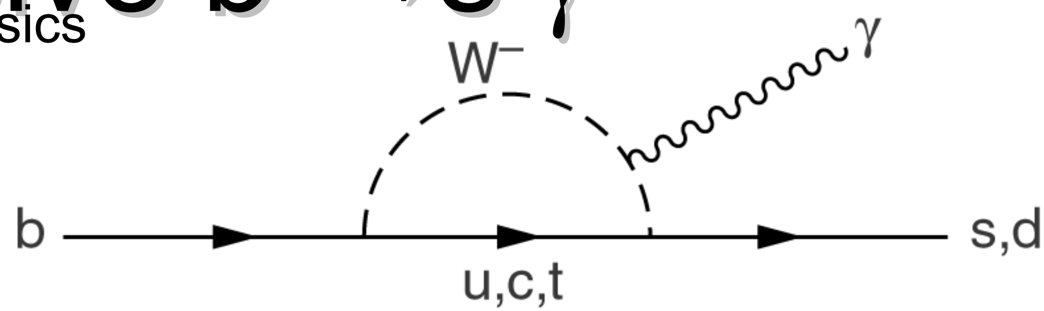
  in inclusive processes H+ exchange small correction, in exclusive – maybe 2 times bigger than W+!!! – in agreement with data
- Consider H+ in 2HDM (II) – large tan beta

Jeffrey Berryhill (FNAL) on behalf of other WG2 editors and contributors

- Radiative penguin B decays ($b \rightarrow s,d\ \gamma$)
- Electroweak penguin B decays ($b \rightarrow s\ l^+ l^-$)
- Rare B decays with taus or neutrinos ($B \rightarrow \tau\nu$, $b \rightarrow s\nu\nu$)
- Very rare leptonic B decays ($B_s \rightarrow \mu\mu$)

Inclusive b →s γ

A “Standard Candle” of flavor physics



Sensitive to top quark couplings
V_{td}, V_{ts}

Photon is DIS probe of B (shape function, m_B)

Broad sensitivity to new physics (2HDM, SUSY, LR, LED, little Higgs)

Misiak et al.

$$\mathcal{B}(\bar{B} \to X_s\gamma)_{E_\gamma > 1.6\,\mathrm{GeV}} = \mathcal{B}(\bar{B} \to X_c e\bar{\nu})_{\mathrm{exp}} \left[\frac{\Gamma(b\to s\gamma)}{\Gamma(b\to ce\bar{\nu})}\right]_{\mathrm{LO\ EW}} f\left(\frac{\alpha_s(M_W)}{\alpha_s(m_b)}\right) \times$$

$$\times \left\{ 1 + \underbrace{\underset{\substack{\mathbf{NLO} \\ \sim 30\%}}{\mathcal{O}(\alpha_s)} + \underset{\substack{\mathbf{NNLO} \\ \sim 10\%}}{\mathcal{O}(\alpha_s^2)} + \underset{\sim 4\%}{\mathcal{O}(\alpha_{\mathrm{em}})}}_{\text{perturbative corrections}} + \underbrace{\underset{\sim 1\%}{\mathcal{O}\left(\frac{\Lambda^2}{m_b^2}\right)} + \underset{\sim 3\%}{\mathcal{O}\left(\frac{\Lambda^2}{m_c^2}\right)} + \underset{\sim 5\%}{\mathcal{O}\left(\frac{\Lambda}{m_b}\alpha_s\right)}}_{\text{non-perturbative corrections}} \right\}$$

(methods: Optical Theorem,
Operator Product Expansion,
Heavy Quark Effective Theory)

Need NNLO precision to compare with experiment

Recent estimate of NNLO decay rate!

Inclusive b →s γ

Misiak et al.

In collaboration with: H.M. Asatrian, K. Bieri, M. Czakon, A. Czarnecki, T. Ewerth, A. Ferroglia, P. Gambino, M. Gorbahn, C. Greub, U. Haisch, A. Hovhannisyan, T. Hurth, A. Mitov, V. Poghosyan, M. Ślusarczyk and M. Steinhauser.

hep-ph/0609232

$$\mathcal{B}(\bar{B} \to X_s\gamma)^{\rm NNLO}_{E_\gamma>1.6\ {\rm GeV}} = (3.15 \pm 0.23) \times 10^{-4}$$

7.3% precision at NNLO

5% non-perturbative $\mathcal{O}\left(\alpha_s \frac{\Lambda}{m_b}\right)$ ← See e.g. hep-ph/0609224

3% parametric $(\alpha_s(M_Z),\ \mathcal{B}^{\rm exp}_{\rm semileptonic},\ m_c,\ \ldots)$

2.0% ($\alpha_s(M_Z)$), 1.6% ($\mathcal{B}^{\rm exp}_{\rm semileptonic}$), 1.1% ($m_c$)

3% m_c-interpolation ambiguity

3% higher order $\mathcal{O}(\alpha_s^3)$

P.S. :Becher & Neubert, hep-ph/0610067: -5% shift from 2-loop corrections at intermediate and soft scales

$$\mathrm{Br}(\bar{B} \to X_s\gamma) = (2.98 \pm 0.26) \cdot 10^{-4}$$

Inclusive b →s γ

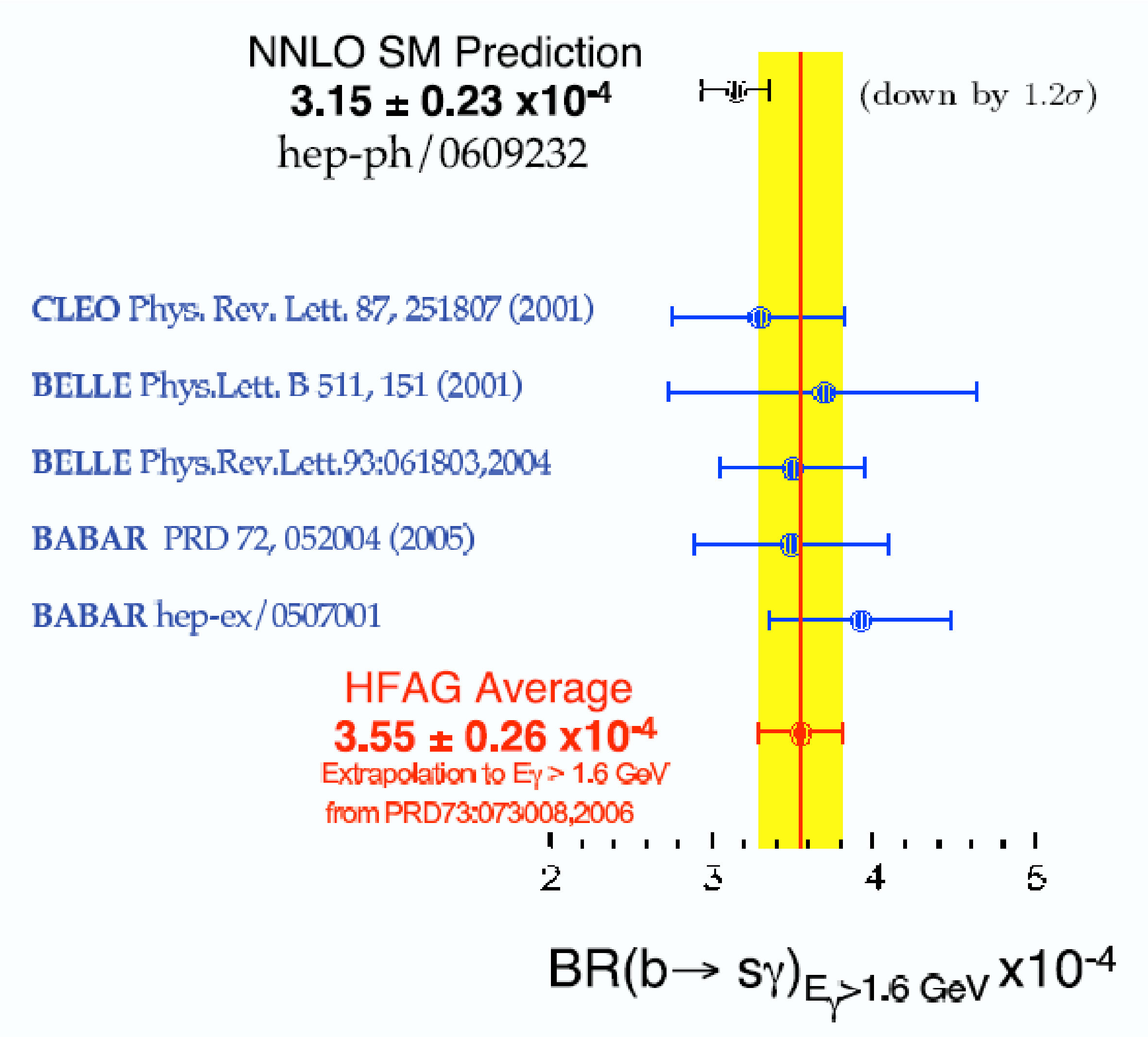
Experiment – NNLO Theory
= +1.2σ

B factories
are likely to improve
precision to 5%

Super B could push
down Eγ cutoff from current
1.8 GeV to 1.5 GeV

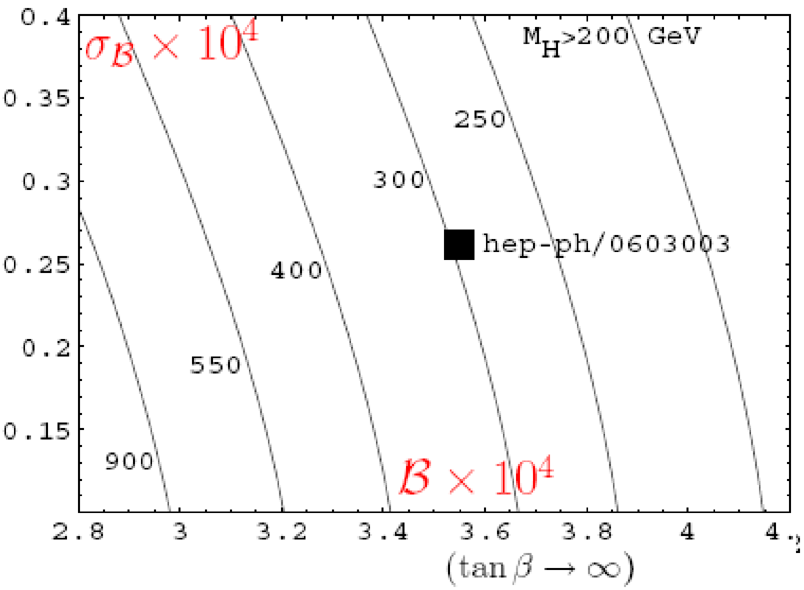
Super B incl. ACP precision:
0.9 % @ 5 ab^{-1}
0.3% @ 50ab^{-1}

Super B can measure incl.
b →dγ rate to
25% with 5 ab^{-1}

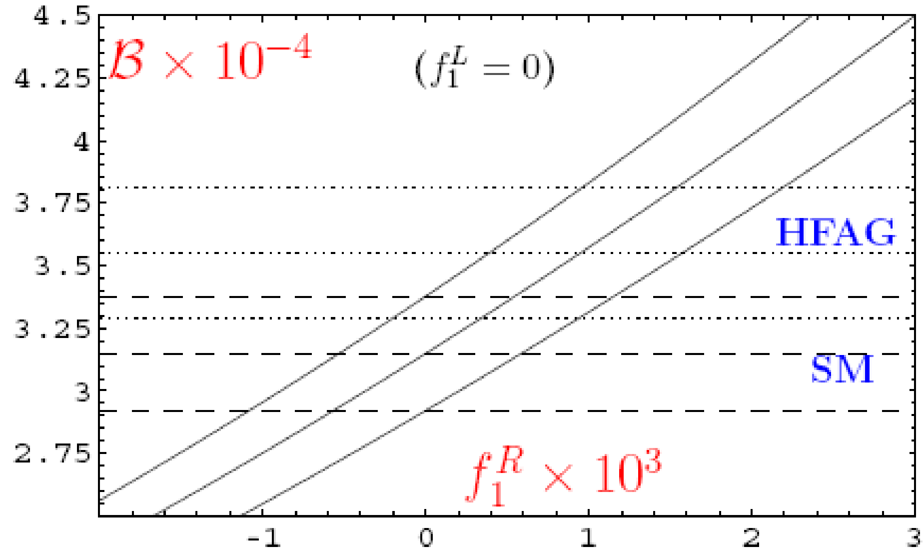


Inclusive b → s γ

2HDM II Limit



Right handed Wtb coupling



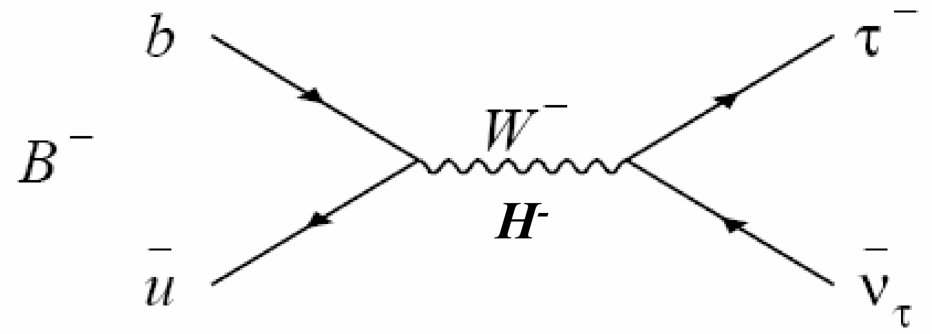
$f^R \sim 10^{-3}$

$M_{H+} > 295$ **GeV @95% C.L.**

MSSM limits to be (re)evaluated: ideally NLO w/ minimal and general flavor violation

B+ → $\tau^+\nu$

Simple decay through weak annihilation



Sensitive to B decay constant f_B or to charged Higgs boson

$$\mathcal{B}(B_u \to \tau\nu)^{\rm SM} = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1-\frac{m_\tau^2}{m_B^2}\right)^2 f_B^2|V_{ub}|^2\tau_B = (1.59 \pm 0.40)\times 10^{-4}$$

$\tan^4\beta$ modifications in 2HDM II model:

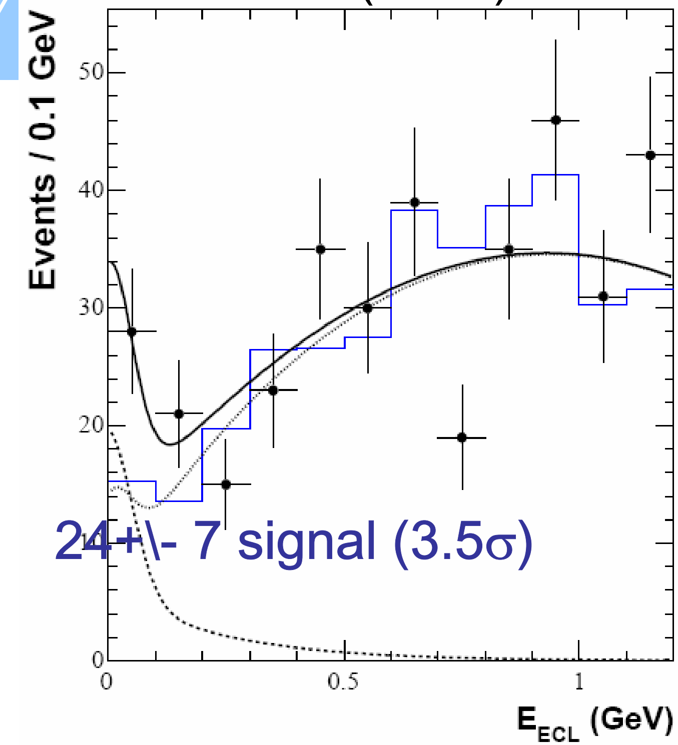
$$R_{B\tau\nu} = \frac{\mathcal{B}(B_u \to \tau\nu)}{\mathcal{B}(B_u \to \tau\nu)^{\rm SM}} = r_H = \left[1 - \tan^2\beta\,\frac{m_B^2}{m_{H^\pm}^2}\right]^2$$

f_B dependence can be removed via ratio with Δm_d, error shrinks 25% → <13% (Isidori & Paradisi)

$$\left.\frac{\mathcal{B}(B_u \to \tau\nu)}{\tau_B \Delta M_{B_d}}\right|^{\rm SM} = 1.77\times 10^{-4}\left(\frac{|V_{ub}/V_{td}|}{0.464}\right)^2\left(\frac{0.836}{\hat{B}_{B_d}}\right)$$

$B^+ \rightarrow \tau^+ \nu$

Belle PRL 97 (2006) 251802

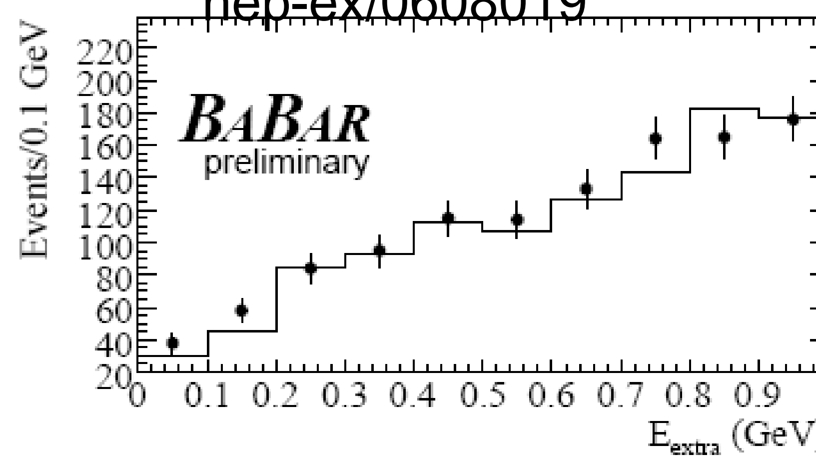


24+\- 7 signal (3.5σ)

<u>Tag side reco of:</u>
hadronic B decay (Belle, ε = 0.15%)
or D^0 l X ν decay (BaBar, ε = 0.6%)

& signal side τ
(Belle: leptonic or 1- or 3-prong, ε = 16%)
(BaBar: leptonic or 1-prong, ε = 13%)
& no other tracks & small extra ECAL energy

hep-ex/0608019

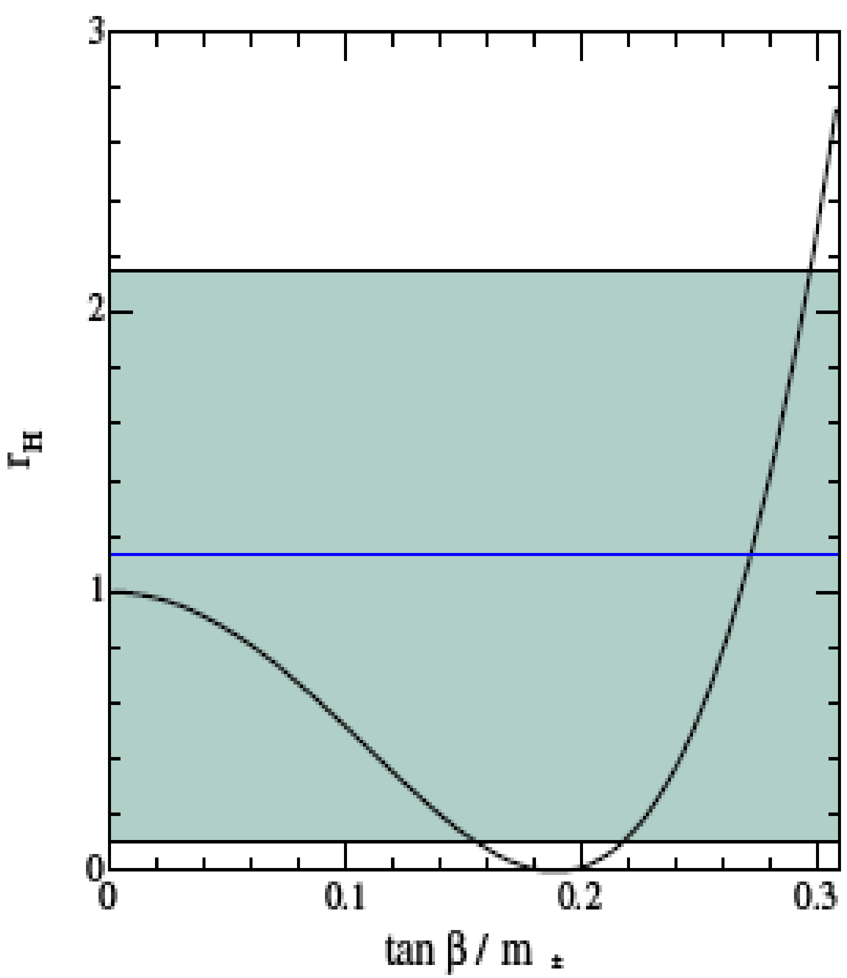


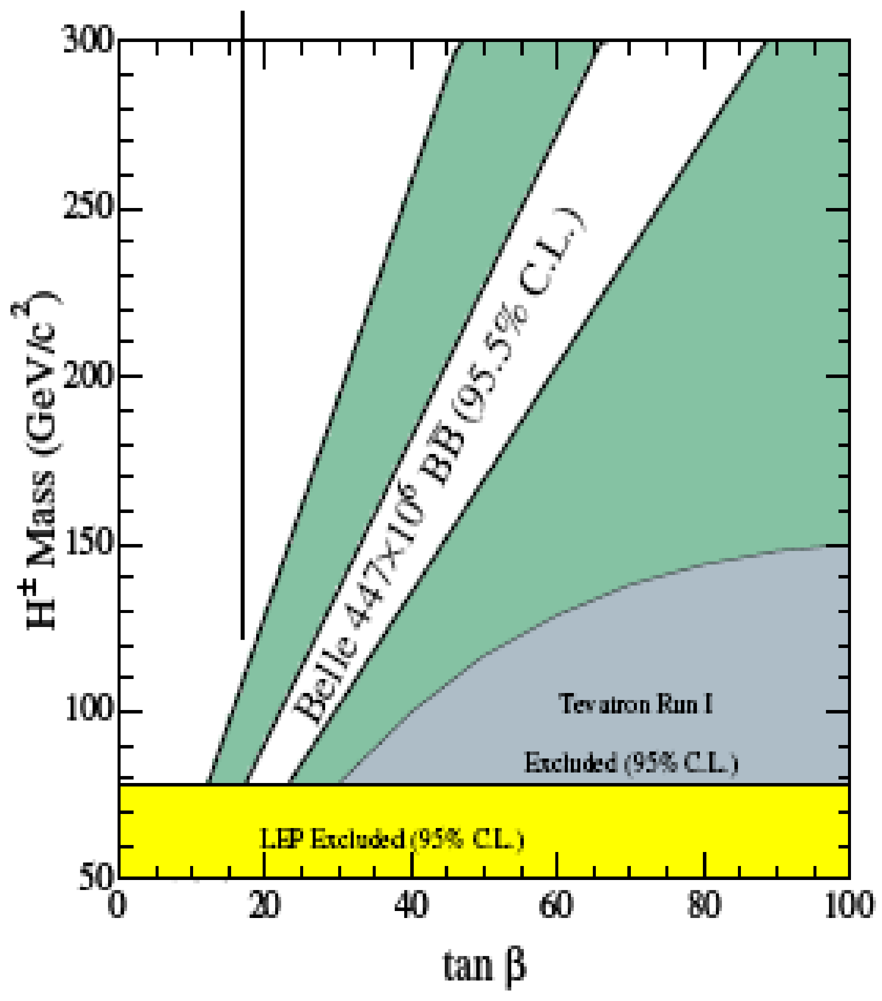
HFAG BF($B \rightarrow \tau\nu$) = 1.34 ± 0.48 10^{-4}

Consistent with SM.

$B^+ \to \tau^+\nu$

Belle result excludes (at tan β = 30) M(H+) < 100, 130 < M(H+) < 190 GeV



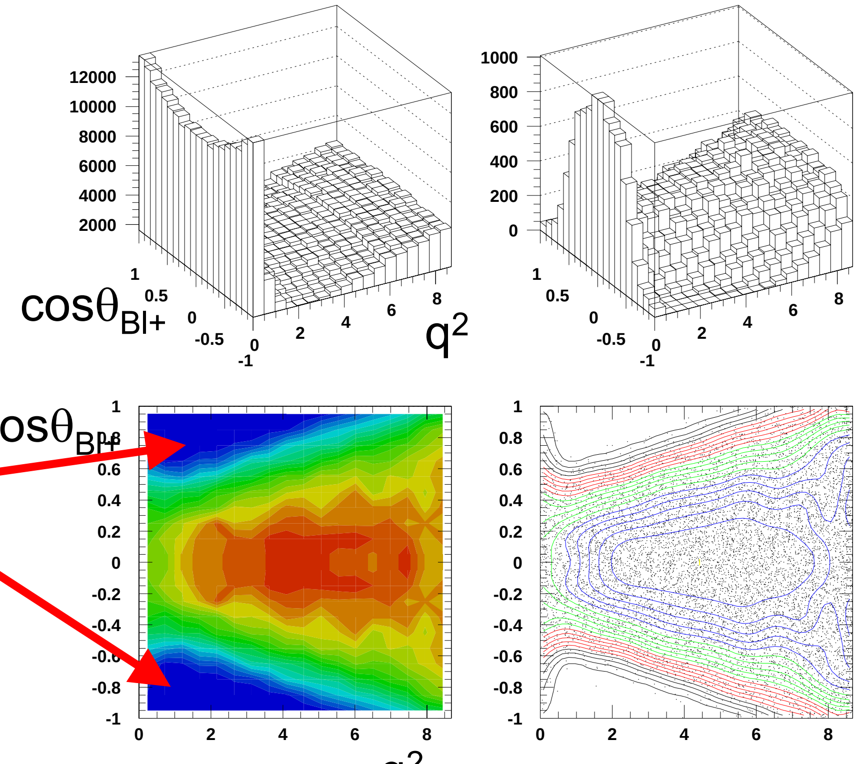


Probability Density Functions

$$\begin{aligned} PDF = \; & f_{sig} \times P_{theory}(A_7,A_9,A_{10};q^2,\cos\theta)/N(A_7,A_9,A_{10}) \times \varepsilon(q^2,\cos\theta) \\ & + (1 - f_{sig} - f_{psi} - f_{K^*hh}) \times P_{dilepton}(q^2,\cos\theta) \\ & + f_{psi} \times P_{psi}(q^2,\cos\theta) \\ & + f_{K^*hh} \times P_{K^*hh}(q^2,\cos\theta) \end{aligned}$$

$K^*\mu\mu$ Signal PDF for q^2 below J/psi veto window

P_{theory} $\quad$ $P_{theory} \times \varepsilon$



$P_{theory} \times \varepsilon$ $\quad$ $P_{theory} \times \varepsilon$

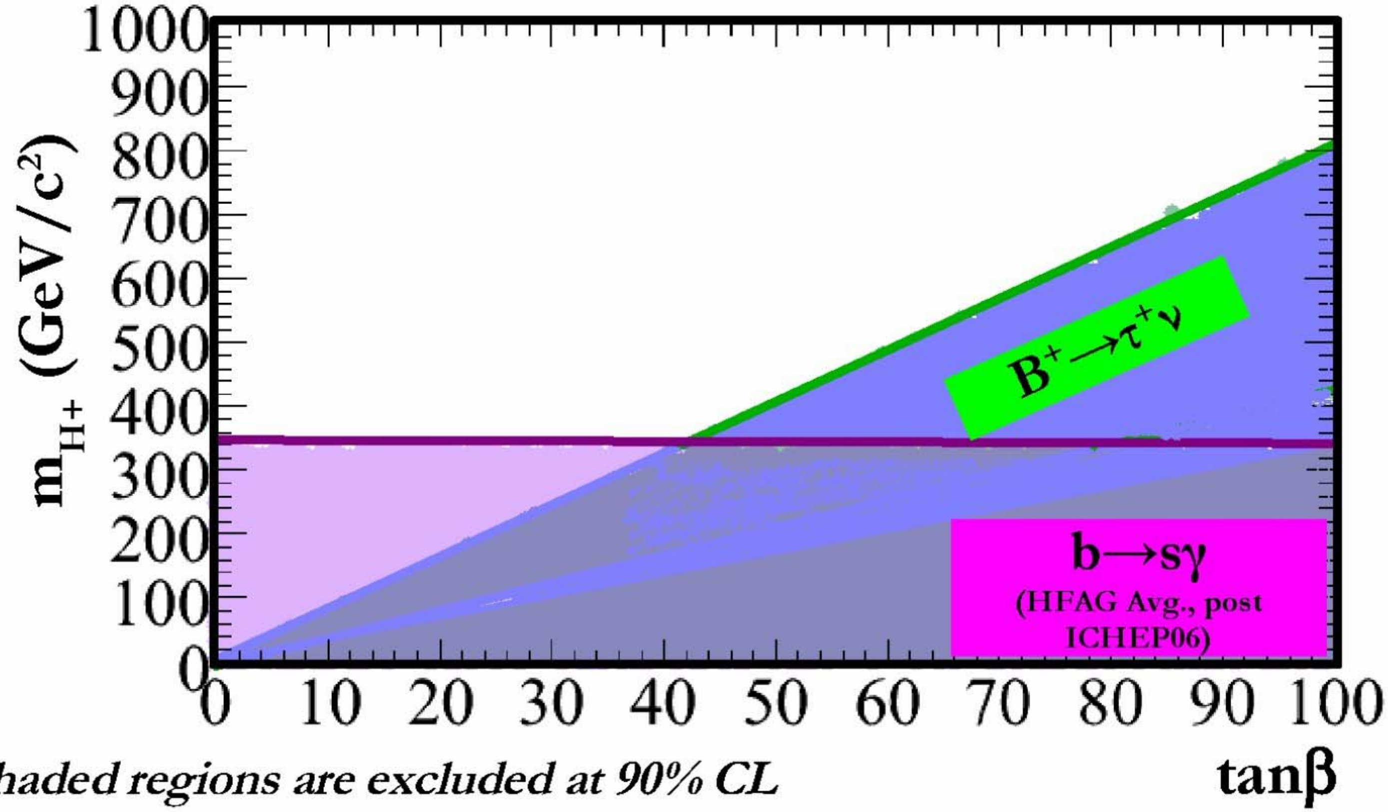
We can not measure low q^2 and high $\cos\theta_{Bl+}$ event since one of muon is low momentum.

So we need muon detector for low momentum region.

(Acceptance for electron modes are a bit better.)

MK'07

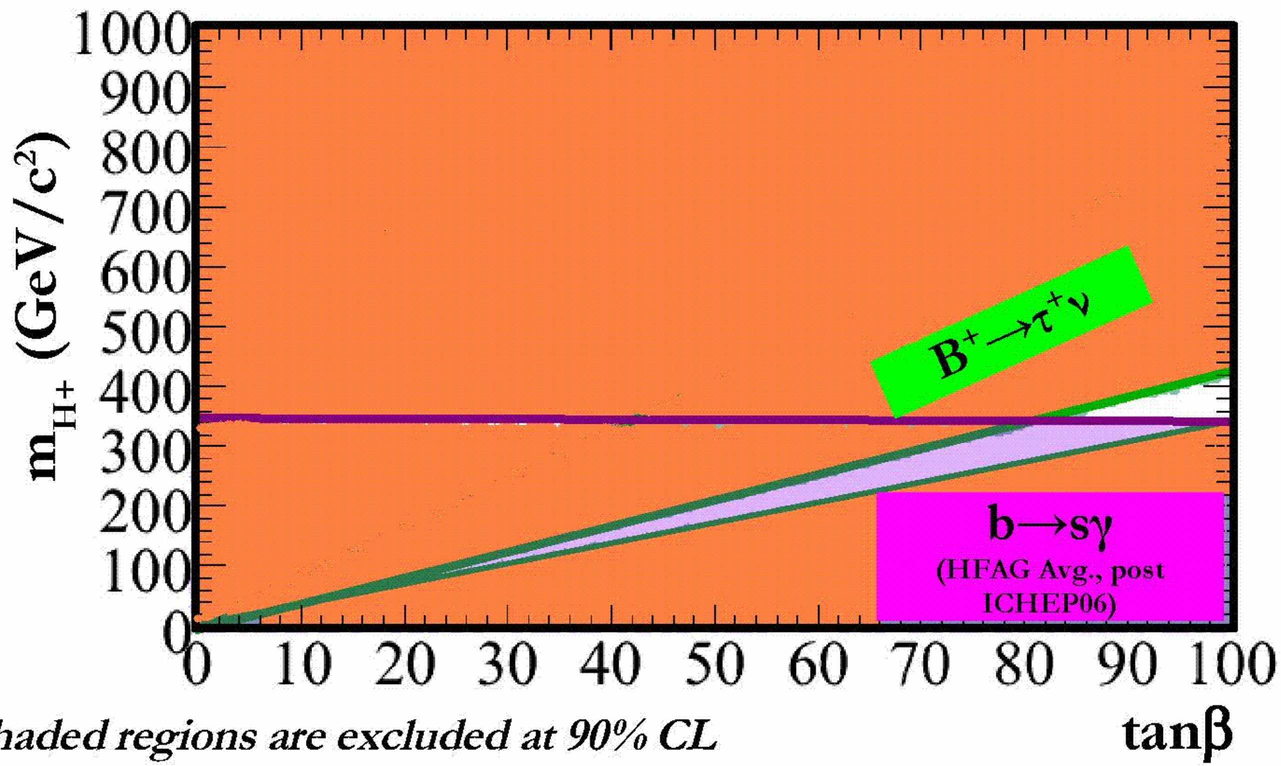
Current Constraints on 2HDM



Shaded regions are excluded at 90% CL

MK'07

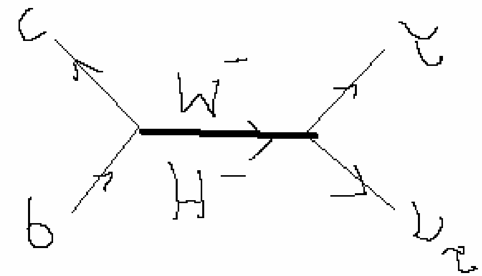
Current Constraints on 2HDM



Shaded regions are excluded at 90% CL

Compare with inclusive decay

$$B \to X_c \tau \nu_\tau$$



The decay rate is different from the exclusive case

$$R_{bc\tau\nu} = 1 - 2m_\tau^2 \frac{\tan^2\beta}{M_{H^\pm}^2} + m_b^2 m_\tau^2 \frac{\tan^4\beta}{4M_{H^\pm}^4}$$

Corrections small, only small x solution

$$x = \tan^2 / M_{H^\pm}^2$$

$$R_{B\tau\nu} = \frac{\mathcal{B}(B_u \to \tau\nu)}{\mathcal{B}(B_u \to \tau\nu)^{\mathrm{SM}}} = r_H = \left[1 - \tan^2\beta \, \frac{m_B^2}{m_{H^\pm}^2}\right]^2$$

Why?

- In the exclusive case –

in SM helicity suppressed decay –

so W- exchange prop. to m_tau/m_b

in H+ exchange – there is also prop to m_tau

So, they are equally important and

$(1- X)^2 = 1$ has two solutions $X=0$ and $X=2$

($X=x\, m_B^2$)

(H+ gives 2 times bigger than W contribution)

Conclusion

- SM is great, in full agreement with data
- Nevertheless new physics effects in rare may be large, even larger than the SM – tree level prediction
- Be careful