Radiative and Leptonic B Decays

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Outline

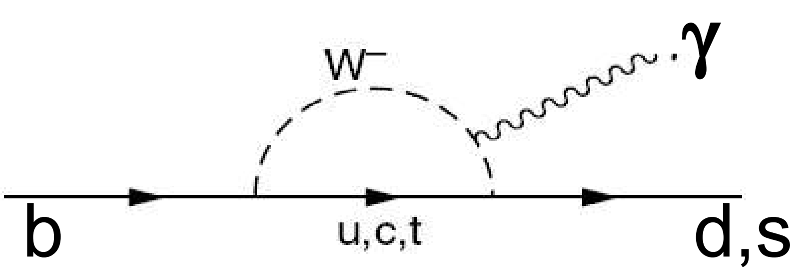
- Radiative Penguin B Decays
  - Status of $b \to s\gamma$
  - Status of $b \to d\gamma$
- Electroweak Penguin B Decays - $b \to s l^+ l^-$
  - Angular measurements in K*ll
- Leptonic B Decays - $B \to \tau\nu$
  - Constraints on the Higgs Mass (with $b \to s\gamma$)

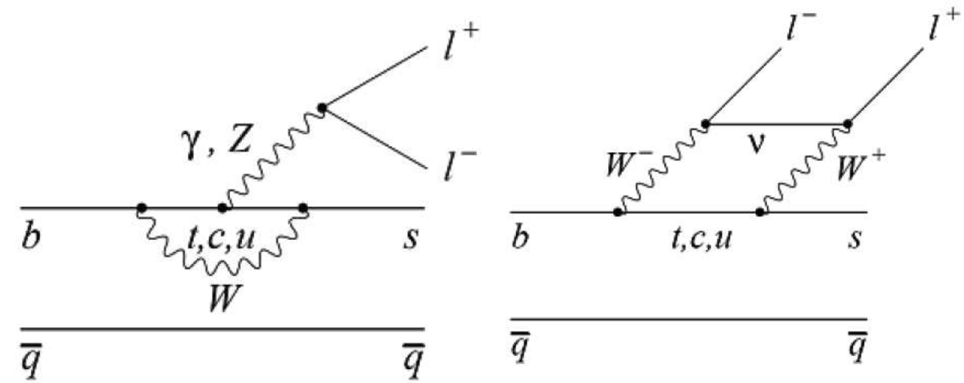
Introduction

- Rare decay searches at the B-factories allow us to probe the flavor sector of the Standard Model
- Penguin processes are of interest because they occur to first order at the loop level. New physics can enter the loop and enhance SM expectations.
- If enhancements are not visible and the LHC finds new physics then this gives rise to the "flavor problem" - new physics can only have subtle effects in the flavor sector.

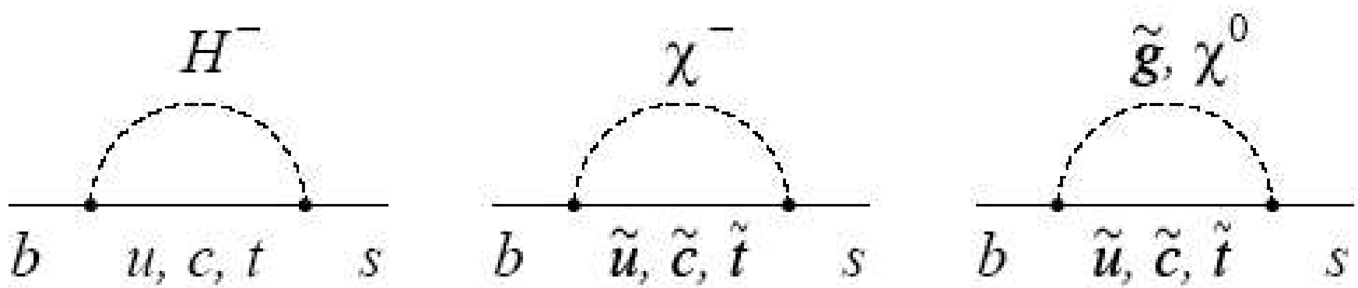
Motivation: b → s,d Penguins

Flavour Changing Neutral Currents allow us to probe SM at 1 loop level





Possible NP can enter loop at leading order:



Status of b $\to$ sγ

- If new physics enters the loop, then the first place we should look is b $\to$ sγ
- Precision measurements put strong constraints on a variety of new physics models
- SM branching fractions:

T. Hurth, E. Lunghi, W. Porod, Nucl. Phys. B 704, 56 (2005).

$$B(\overline{B} \to X_s\gamma) = \left(3.61\,{}^{+0.24}_{-0.40}\Big|_{m_c/m_b} \pm 0.02_{\rm CKM} \pm 0.24_{\rm param} \pm 0.14_{\rm scale}\right) \times 10^{-4}$$

$$A_{CP}(\overline{B} \to X_s\gamma) = (0.42 \pm 0.08_{m_c/m_b} \pm 0.03_{\rm CKM}\,{}^{+0.15}_{-0.08}\Big|_{scale})\%$$

M. Neubert, Eur. Phys. J. C 40, 165 (2005).

$$B(\overline{B} \to X_s\gamma) = \left(3.47\,{}^{+0.33}_{-0.41}\Big|_{\rm pert}\,{}^{+0.32}_{-0.29}\Big|_{\rm param}\right) \times 10^{-4}$$

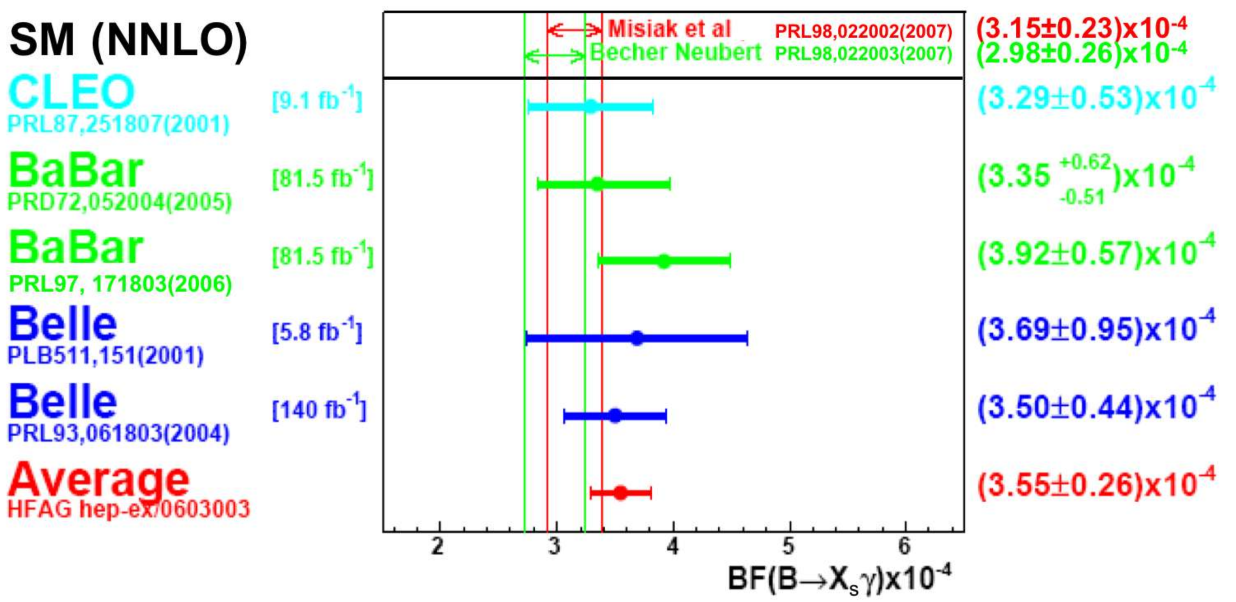
M. Misiak and M. Steinhauser, hep-ph/0609241 NNLO

$$B(\overline{B} \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$$

New!

all for $E_\gamma > 1.6$ GeV

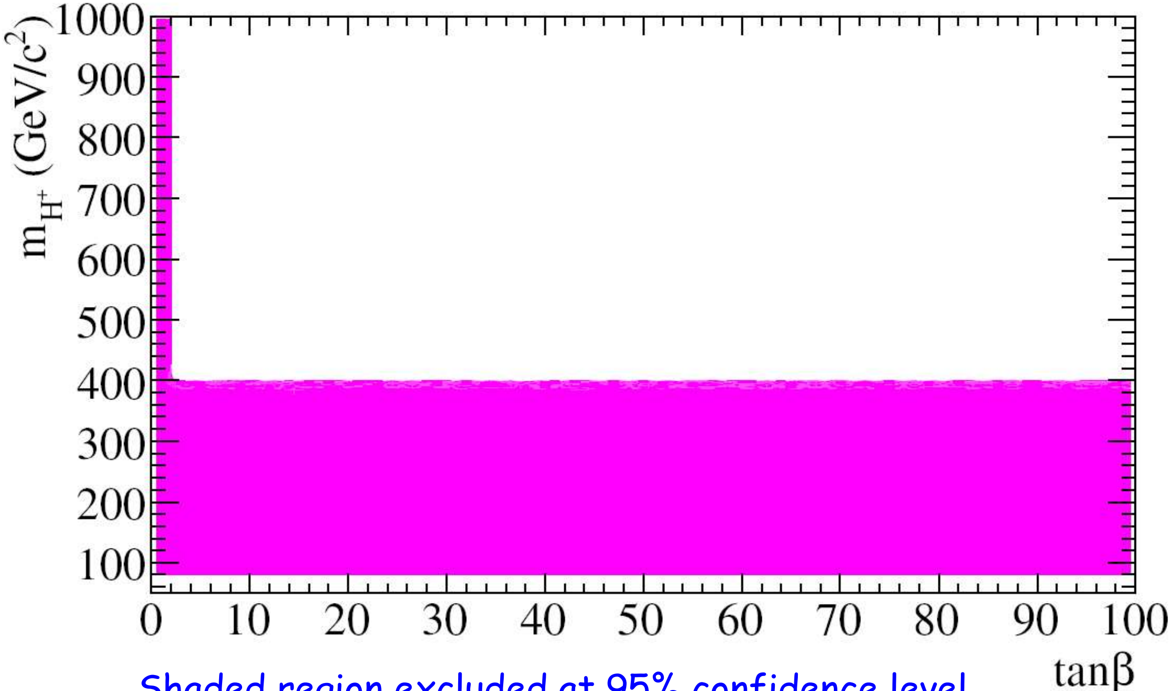
Experimental Measurements



- Proximity to the SM expectation allows for constraints on new physics models
- Other observables are interesting in NP scenarios as well: A_{CP}, Moments
- We can look elsewhere for new physics: $b \to d\gamma$

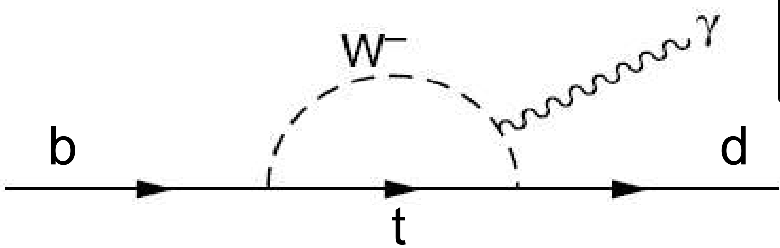
Constraints on 2HDM

- In the type-II two-Higgs Doublet model (2HDM), each Higgs doublet couples to either up-type or down-type quarks and leptons.
- tan(β) is the ratio of the vacuum expectation values
- Measuring the $b \to s\gamma$ BF allows us to place constraints on the 2HDM

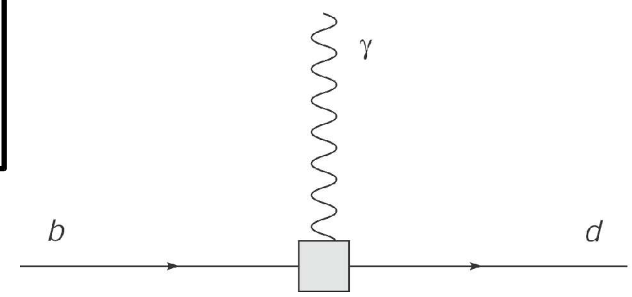


Shaded region excluded at 95% confidence level

$b \to d\gamma$ Motivation



Integrate out heavy fields



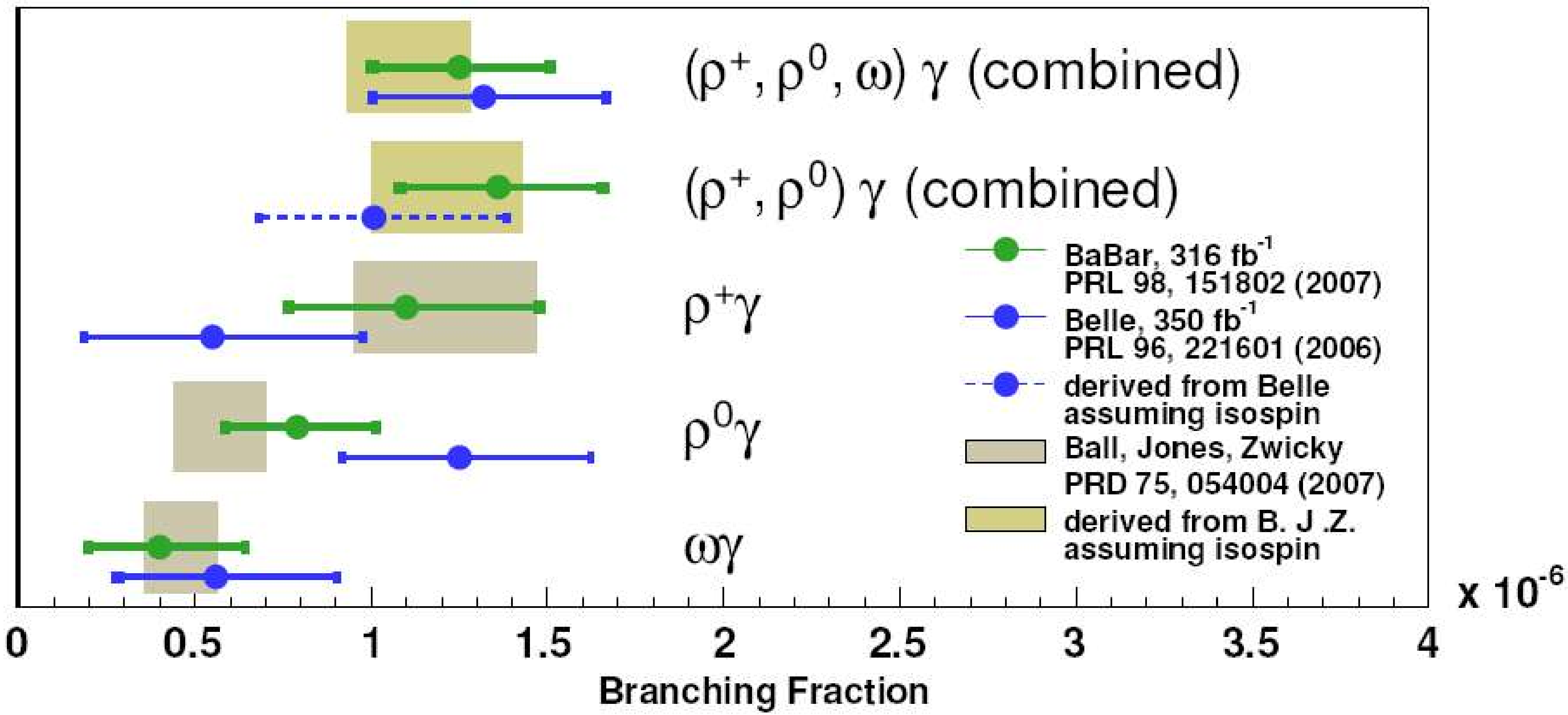
Need to use effective theory:

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{td}^{*} \sum_{i=1}^{8} C_i(\mu)\, \mathcal{O}_i(\mu)$$

- Wilson coefficients (C_i's) describe the short-distant effects (also important in $b \to s l^+ l^-$)
- $b \to d\gamma$ is CKM suppressed
- With B-Mixing, we can constrain the CKM unitary triangle.

Mode	Branching Fraction (SM)
$B \to (\rho^0/\omega)\,\gamma$	$\sim 0.5 \times 10^{-6}$
$B \to \rho^+\gamma$	$\sim 1 \times 10^{-6}$

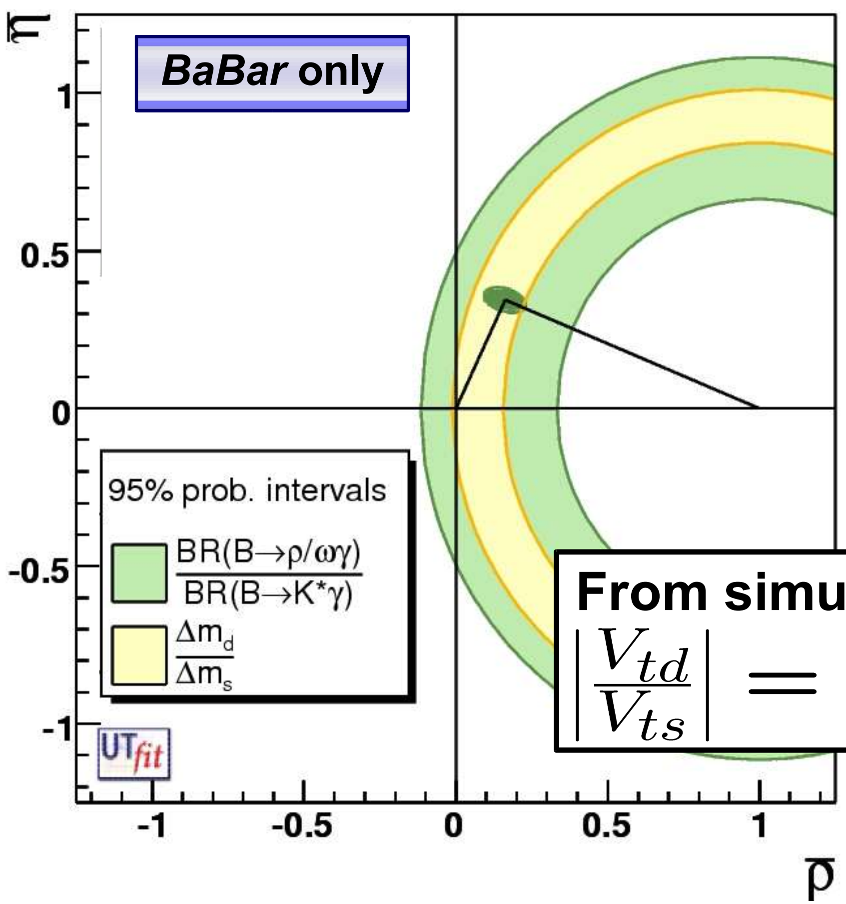
BF Measurements



$b \to d\gamma$: Vtd/Vts

Ratio of $\rho\gamma$, $K^*\gamma$ BFs can be used to extract V_{td}/V_{ts}:

$$\frac{\mathcal{B}(B \to (\rho,\omega)\gamma)}{\mathcal{B}(B \to K^*\gamma)} = \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1 - m^2_{\rho,\omega}/m^2_B}{1 - m^2_{K^*}/m^2_B}\right)^3 \left(\frac{T_1^{\rho,\omega}(0)}{T_1^{K^*}(0)}\right)^2 [1 + \Delta R]$$



- B mixing and $b \to d\gamma$ are independent physics processes used to constrain V_{td}/V_{ts}
- New physics could affect both processes differently!
- No new physics hints here. Let's see what we can do with $b \to sl^+l^-$

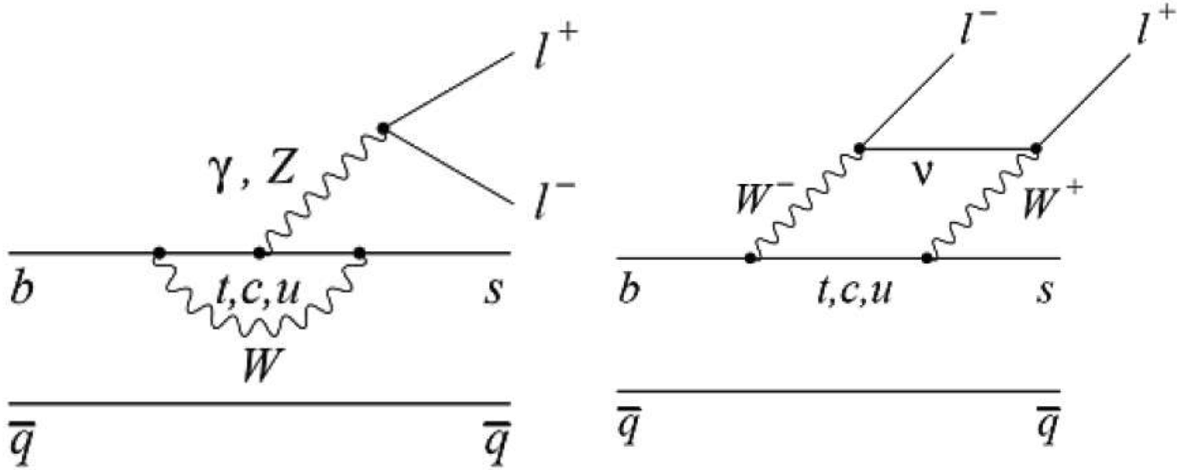
From simultaneous fit result, we compute:

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.200^{+0.021}_{-0.020} \pm 0.015$$

First error experimental and second theoretical.

Electroweak Penguin B Decays

$b \rightarrow sl^+l^-$



Electroweak Penguin B Decays

$b \to sl^+l^-$

$$\mathcal{M} = \frac{G_F\alpha}{\sqrt{2}\pi}V_{tb}V_{ts}^*\left\{\left[C_9^{\rm eff}\langle K\pi|(\bar{s}\gamma^\mu P_L b)|B\rangle - \frac{2m_b}{q^2}\langle K\pi|\bar{s}i\sigma^{\mu\nu}q_\nu(C_7^{\rm eff}P_R + C_7^{\rm eff\prime}P_L)b|B\rangle\right] \times (\bar{l}\gamma_\mu l) + C_{10}\langle K\pi|(\bar{s}\gamma^\mu P_L b)|B\rangle(\bar{l}\gamma_\mu\gamma_5 l)\right\},$$

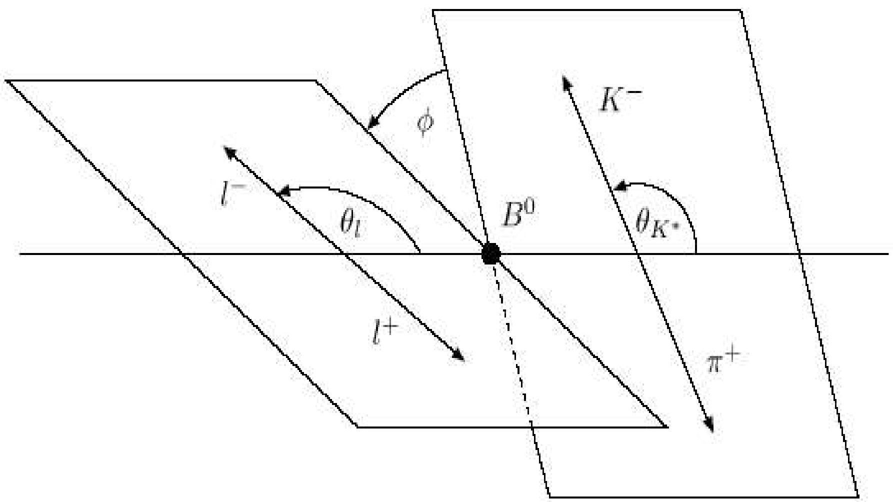
Mix of Z Pen, WW box

Phonton Pen
Dominates at low s

Kruger and Matias; PRD 71, 094009 (2005)

- Short distance physics embedded in the Wilson coefficients (C_i's)
- Interference terms generate asymmetries in lepton angular distribution over most of s

Angular Observables: $B \to K^* l^+ l^-$

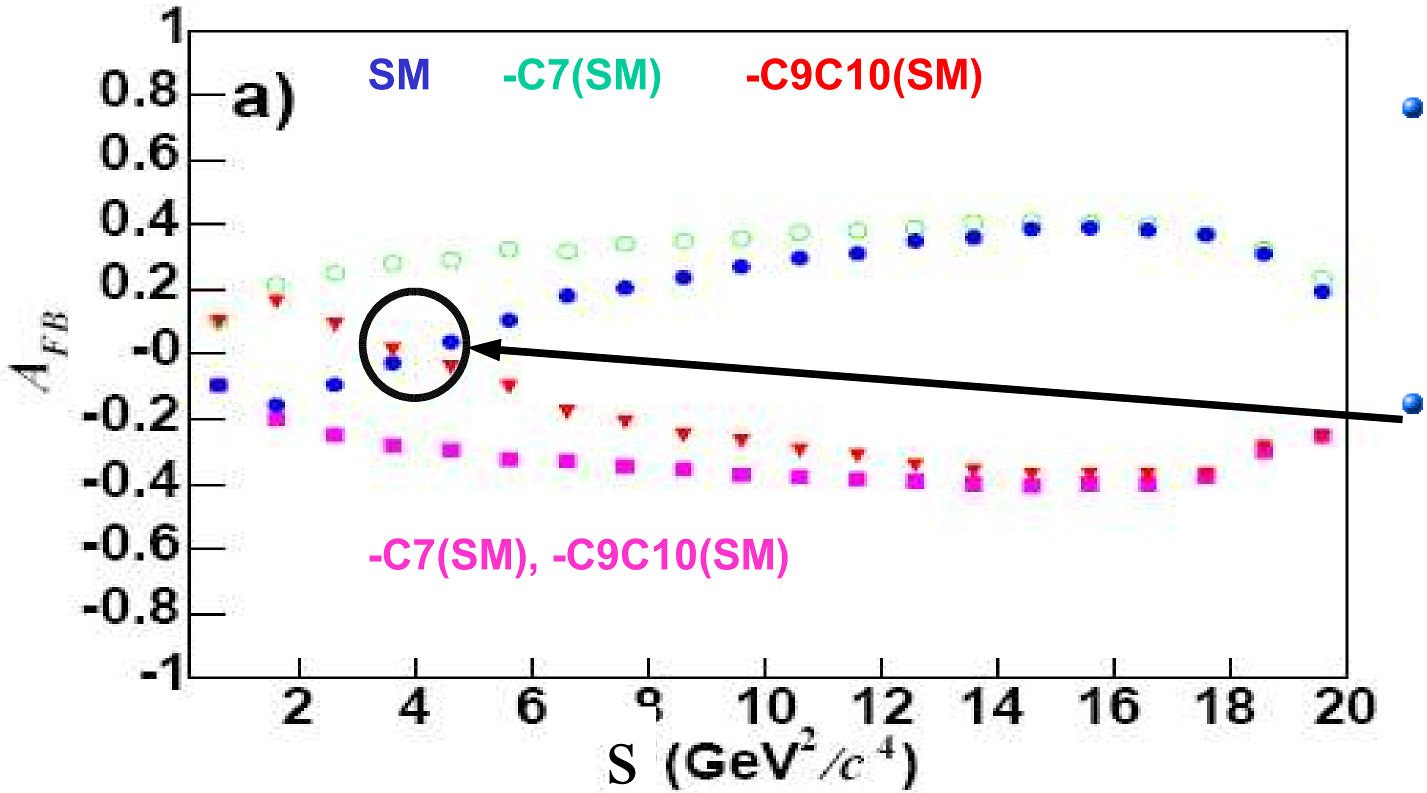


- θ^* - lepton angle in di-lepton rest frame. Forward-backward asymmetric due to axial vector penguin (C10) amplitude.
  - AFB from *b* tagged cos $\theta^*(l^-)$
- θ_k - kaon angle in K* rest frame: K* polarization
- ϕ – angle between K* and di-lepton decay planes

$$\frac{dA_{FB}}{ds} \propto -C_{10}\left\{\Re(C_9^{eff})VA_1 + \frac{m_b m_B}{s}C_7^{eff}\left[VT_2(1-\frac{m_{K^*}}{m_B}) + A_1T_1(1+\frac{m_{K^*}}{m_B})\right]\right\}$$

- $C_9 C_{10}$ Wilson coefficients dominate at high $s = q^2 = m_{ll}^2$
- C_7 Wilson coefficient dominates at low s
- A_{FB} varies strongly as a function of s

A_{FB} in $K^*l^+l^-$

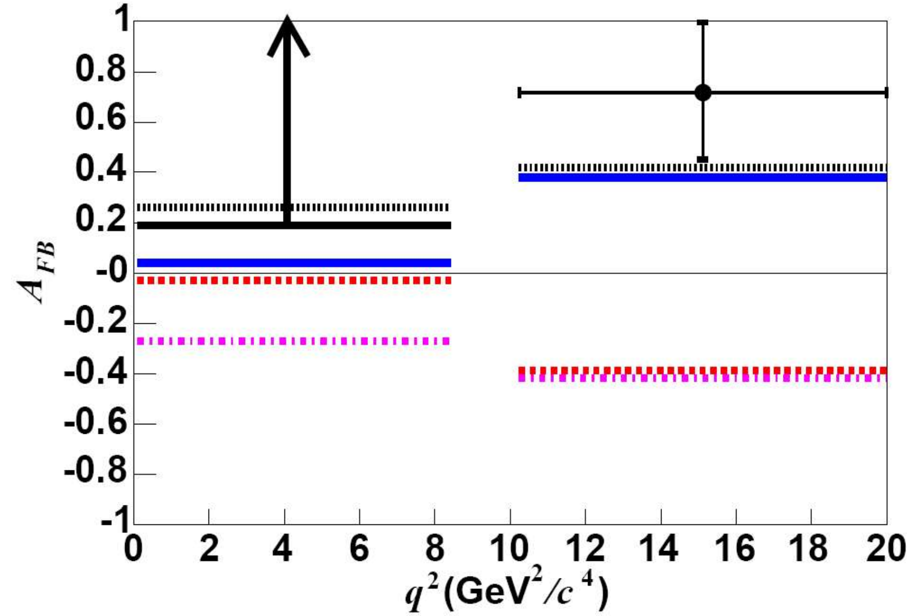


- Wrong sign Wilson coefficient models maximally differ from the SM
- Absence of a 0-crossing would be an indication of new physics

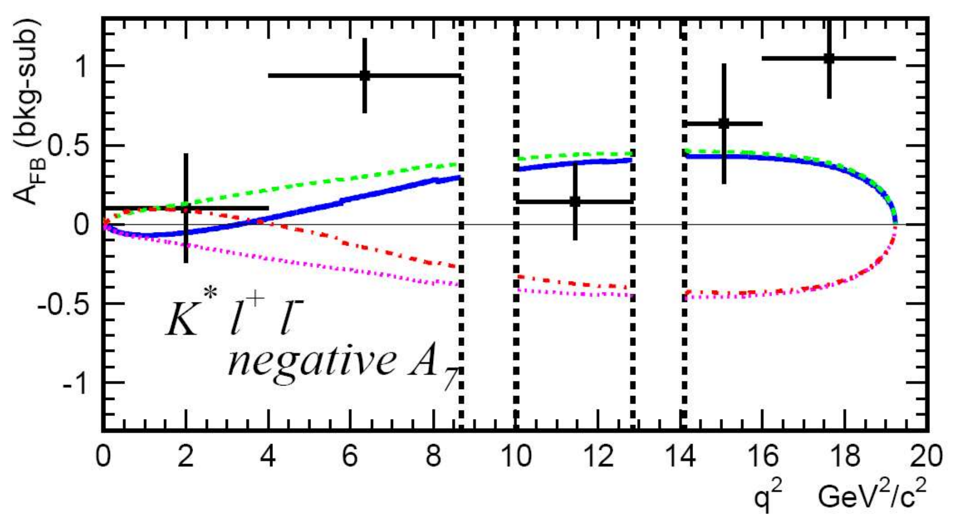
Current Results: $B \to K^* l^+ l^-$

- Current Babar and Belle results have large positive AFB value in all q^2 bins.
- Low q^2 Babar result ~2% consistent with SM value (~0.03)
- By the end of the B-factories lifetimes we will know if there is a AFB 0-crossing
- Precision measurement of the 0-crossing can be done at LHCb or a Super-B factory

- Babar 06, 210/fb K* AFB

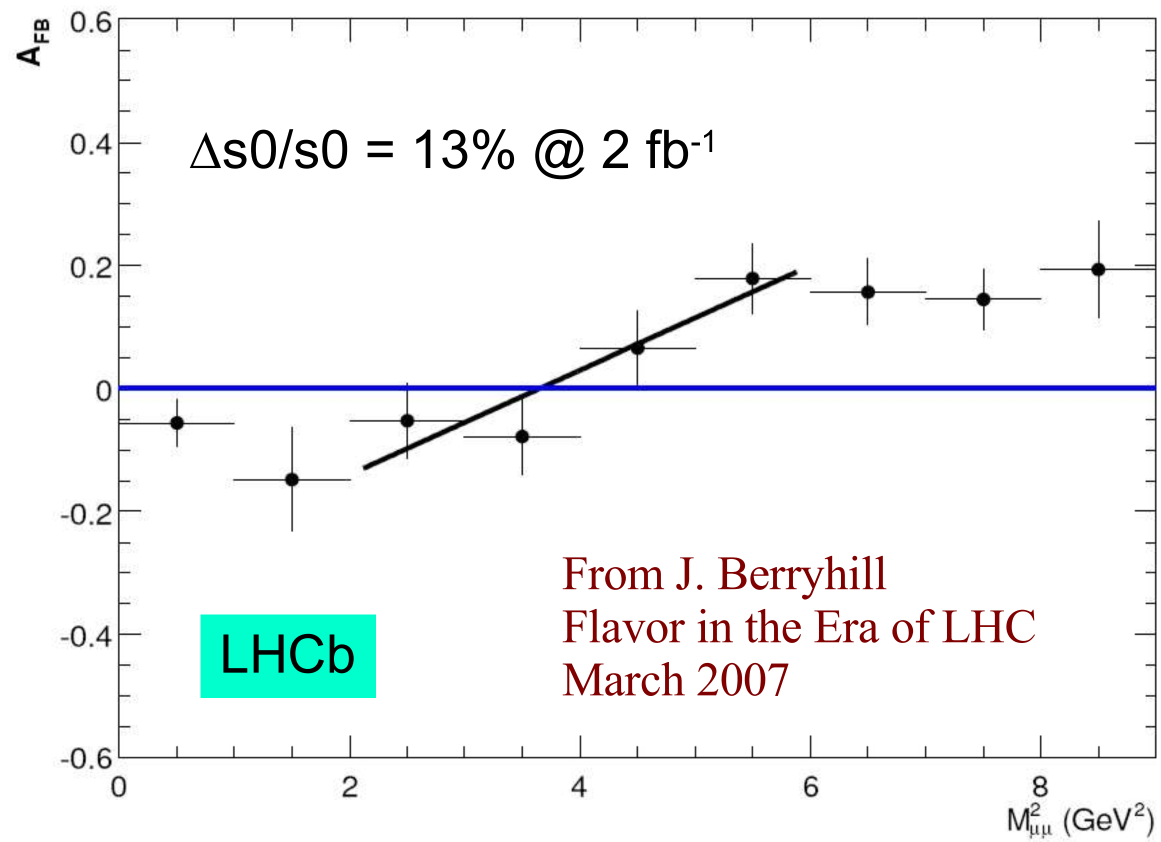


- Belle 05, 357/fb K* AFB

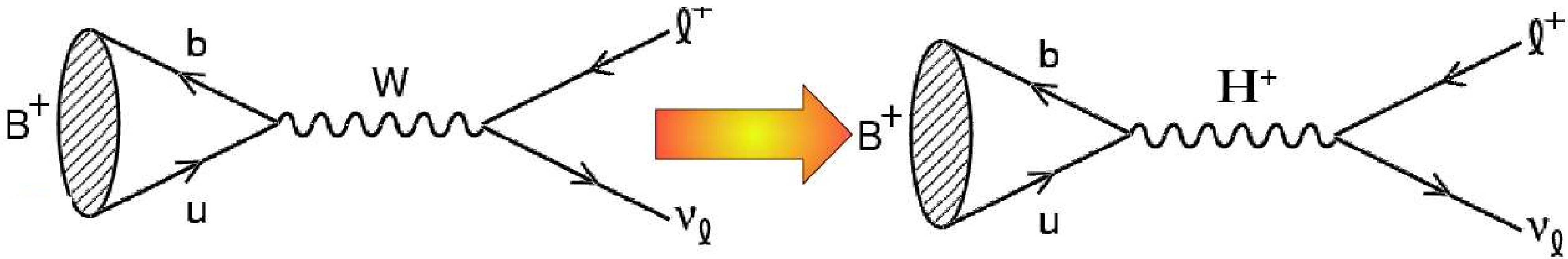


Prospects at LHC(b)

- In 2 fb^{-1} (~1 year):
  7200 signal, 1770 bb background,
  <1730 irreducible $K\pi\, ll$ background (not well known, upper bound from BaBar)
- With bb background only, signal precision is 1.3% @ 2 fb^{-1}
- The 0-crossing can be precisely measured at LHC
- Extract AFB zero from binned linear fit of dA_{FB}/ds from 2-6 GeV^2



Leptonic B Decays at BaBar



$$\mathcal{B}(B^+ \to l^+ \nu_l) = \frac{G_F^2 m_B m_l^2}{8\pi} \left(1 - \frac{m_l^2}{m_B^2}\right) f_B^2 |V_{ub}|^2 \tau_B$$

- $B \to \tau\nu$ unitary constrained BR: $(0.86 \pm 0.15) \times 10^{-4}$
- Current sensitivity to the SM allows us to place constraints on the charged Higgs mass
- Possible BR enhancement or suppression in the type-II two-Higgs Doublet Model (2HDM)

$$BR = BR_{SM} \times \left(1 - \tan^2\beta \frac{m_{B^+}^2}{m_{H^+}^2}\right)^2$$

Current Results: BFs

Belle

$$\mathrm{BF}(B^+ \to \tau^+ \nu_\tau) = 1.79^{+0.56+0.39}_{-0.49-0.46} \times 10^{-4}$$

hep-ex/0604018/PRL

BaBar

Upper Limit:

$$BR(B^+ \to \tau^+ \nu) < 1.8 \times 10^{-4} \text{ at the 90\% CL}$$

hep-ex/0608019/Preliminary

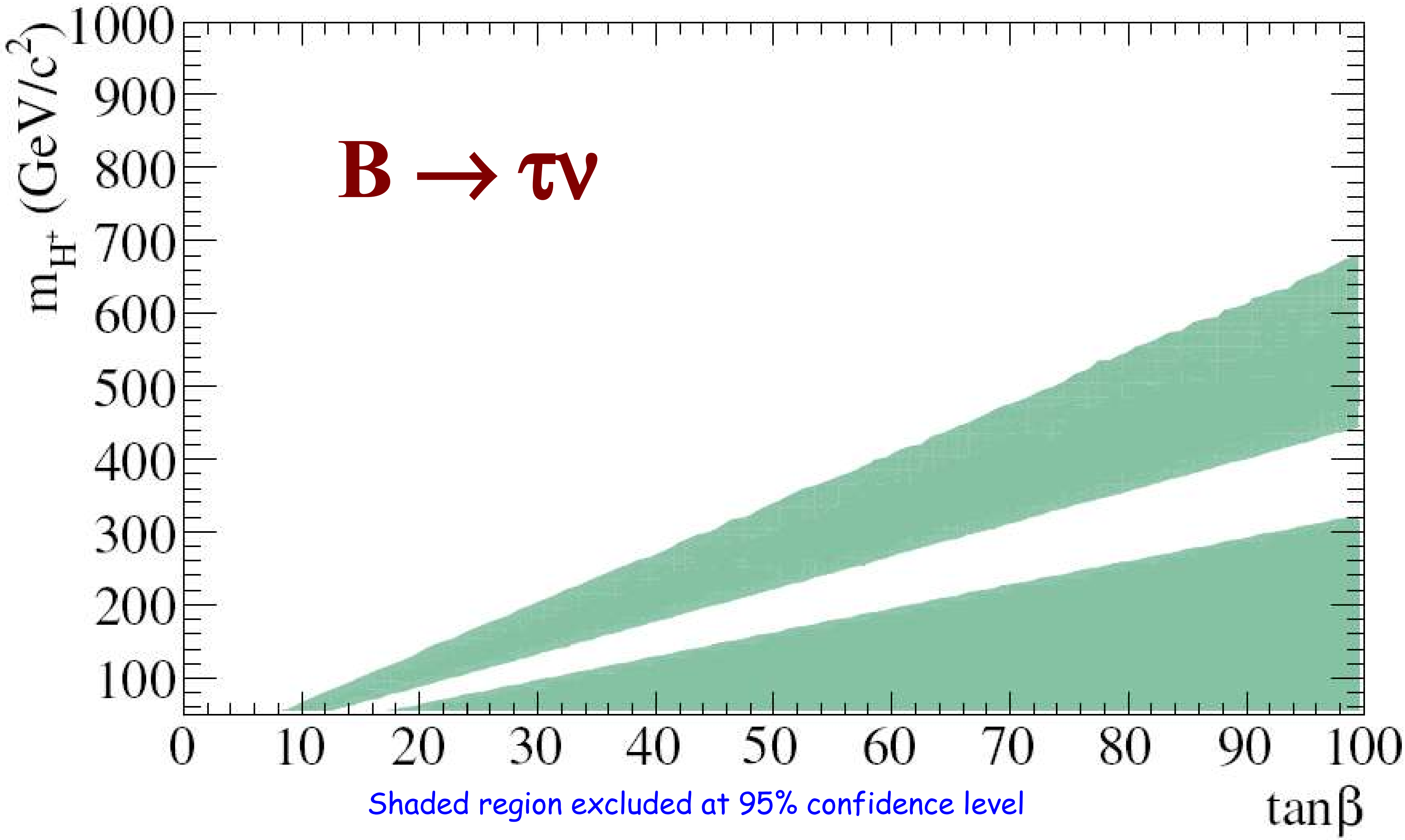
Best Central Value:

$$0.88^{+0.68}_{-0.67}(stat.) \pm 0.11(syst.)$$

HFAG Avg

$$(1.34 \pm 0.48) \times 10^{-4}$$

Current Constraints on 2HDM



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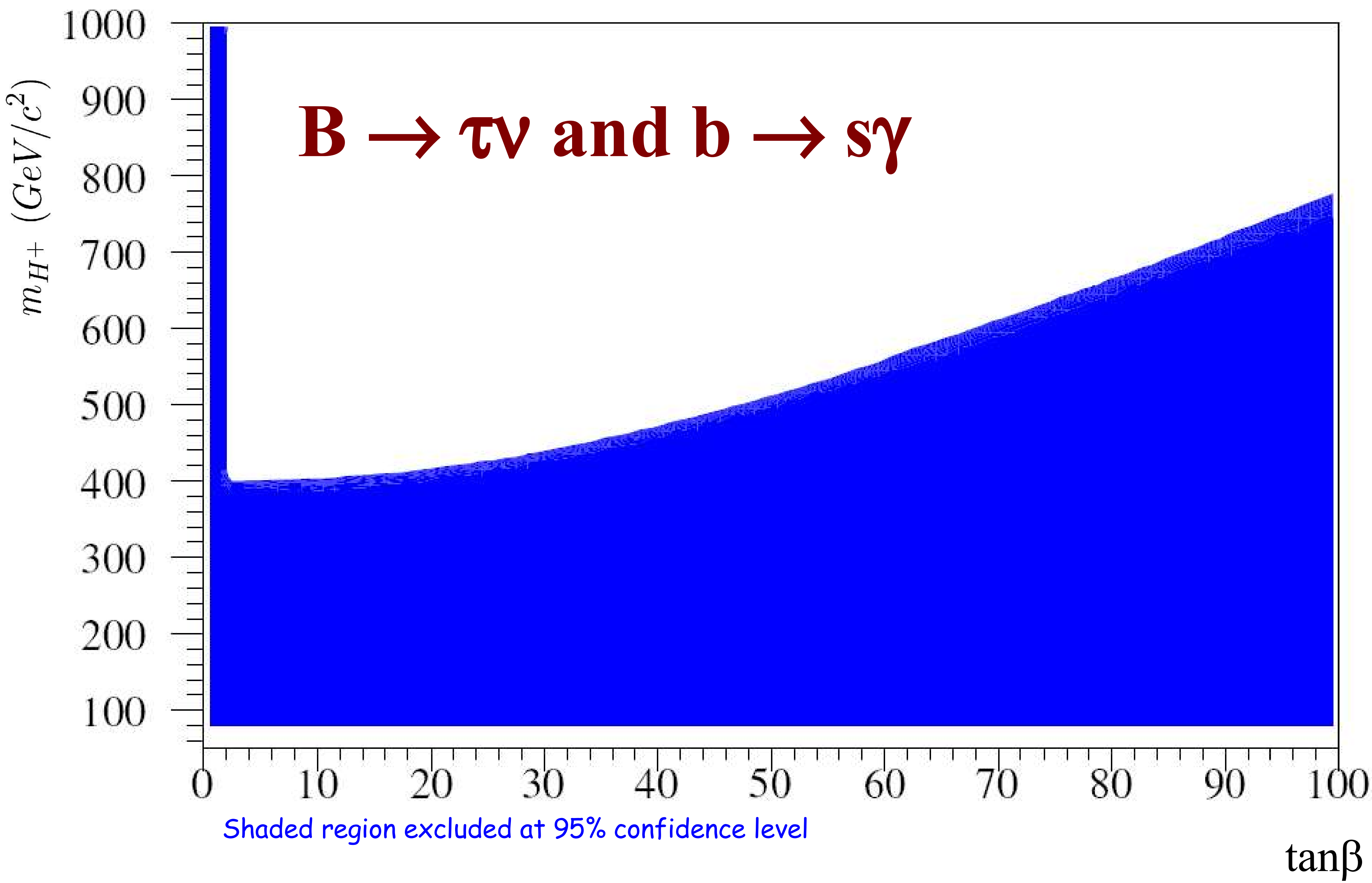
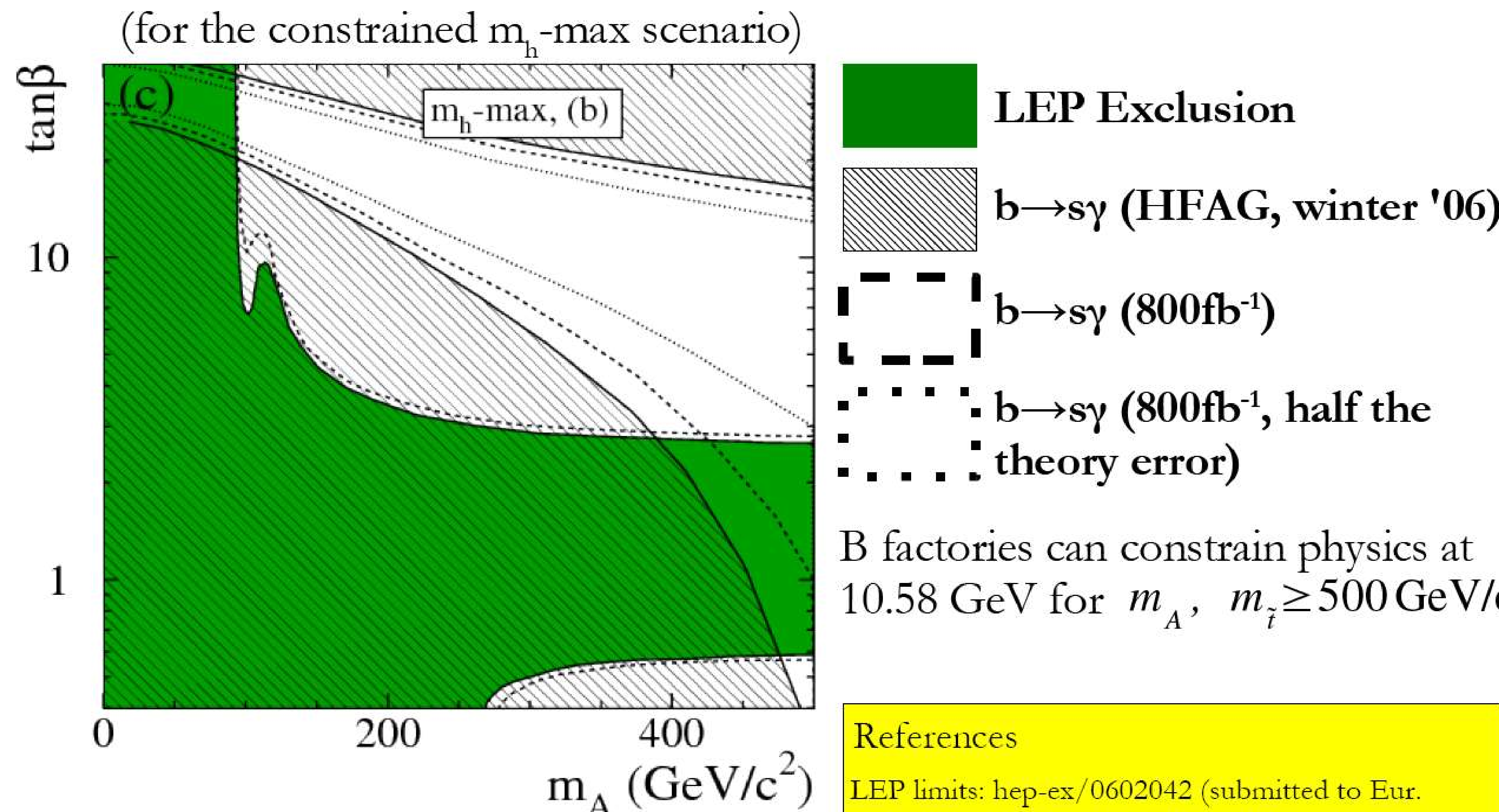
Current Constraints on 2HDM



Conclusions

- If the LHC finds new physics, they will still require information from the B-factories to determine the effect on the flavor sector.
- If the LHC does find new physics, then the effects on the flavor sector will be subtle – "flavor problem".
- Current B-factory measurements allow us to constrain possible new physics at the LHC.
- Some of these constraints depend on assumptions which require information from the LHC.
- Angular measurements in B K*ll will be more accessible at LHC (especially the AFB 0-crossing)

Backup: Constraints on MSSM $b \to s\gamma$



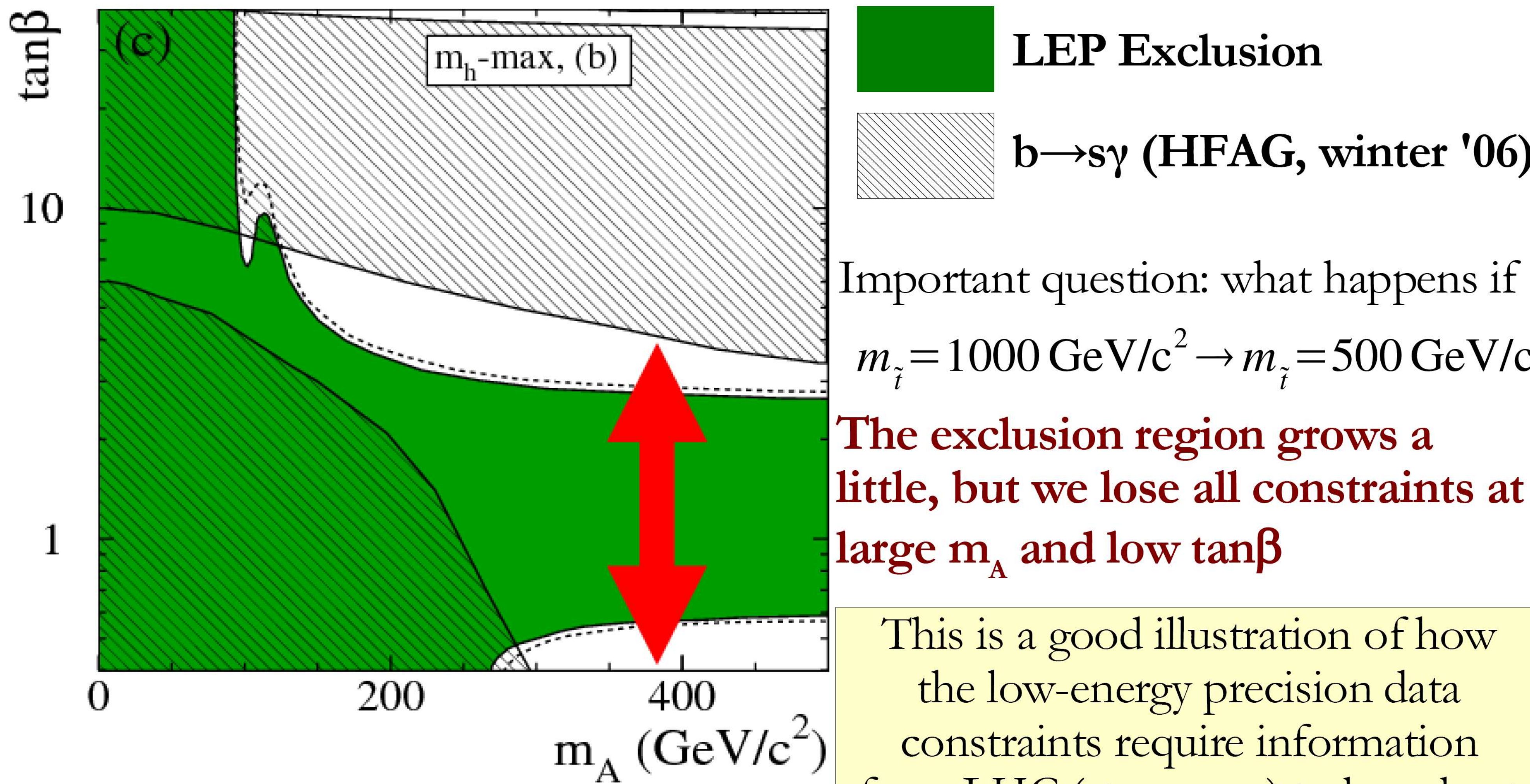
Where in the MSSM: $M_{H+}^2 = m_A^2 + m_W^2$

B factories can constrain physics at 10.58 GeV for $m_A, \; m_{\tilde{t}} \geq 500\,\mathrm{GeV/c^2}$

References

LEP limits: hep-ex/0602042 (submitted to Eur. Phys. J. C)

Backup: b → sγ, LHC, and MSSM



Important question: what happens if

$$m_{\tilde{t}} = 1000\ \mathrm{GeV}/c^2 \rightarrow m_{\tilde{t}} = 500\ \mathrm{GeV}/c^2$$

The exclusion region grows a little, but we lose all constraints at large m_A and low tanβ

This is a good illustration of how the low-energy precision data constraints require information from LHC (stop mass) to be robust

CKM Matrix

Sensitive to far side of Unitarity Triangle:

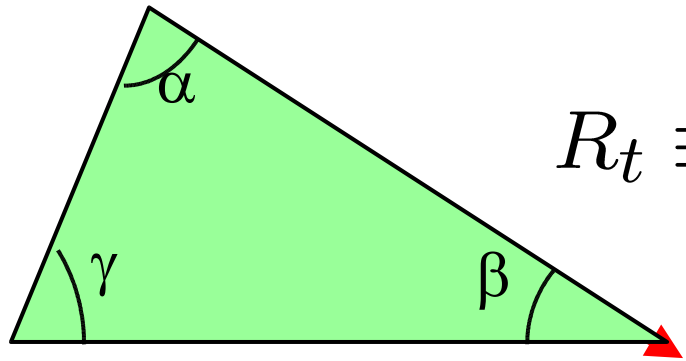
- ***The CKM matrix (Wolfenstein parameterization):***

$$\hat{V}_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\varrho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\varrho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

- ***Unitarity condition of the CKM matrix (↔ conservation of probability):***

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

- ***The far side of the unitarity triangle and $|V_{td}/V_{ts}|^2$***



$$R_t \equiv \frac{|V_{td}V_{tb}^*|}{|V_{cd}V_{cb}^*|} \approx \frac{1}{\lambda}\left|\frac{V_{td}}{V_{cb}}\right| \approx \frac{1}{\lambda}\left|\frac{V_{td}}{V_{ts}}\right|$$