$B \to \tau\nu$ and $B \to D^{(*)}\tau\nu$ at Belle and BaBar

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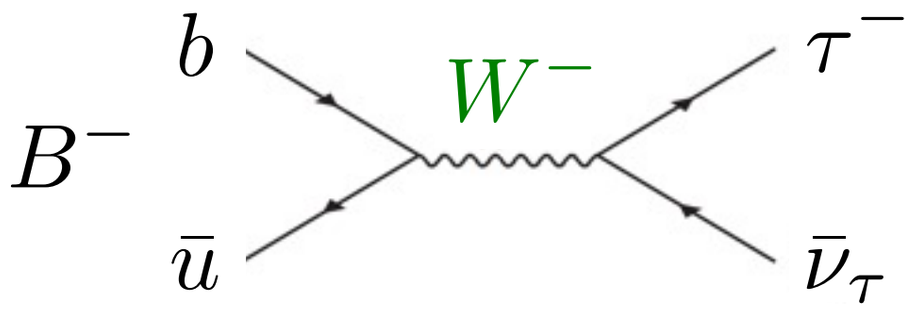
Beauty 2013, 9 Apr 2013, Bologna

B→τν in the Standard Model

- In the SM, annihilation process mediated by $W^{\pm}$.



- The branching ratio is calculated by

$$\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau) = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

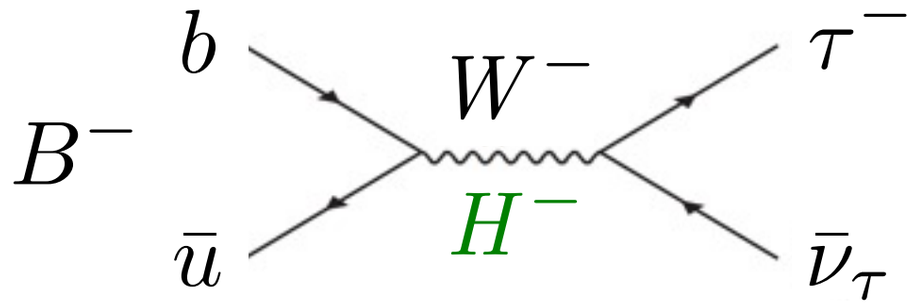
to be about 1×10^{-4} depending on f_B and $|V_{ub}|$. "Helicity suppression"

- f_B: B meson decay constant. f_B=(191±9) MeV *[lattice, HPQCD, PRD86].*
- V_{ub}: CKM matrix element. $|V_{ub}|$=(4.15±0.49)×10^{-3} *[b→ulν, PDG, PRD86].*

Both can also be obtained from a CKM global fit.

Possible Effect of $H^{\pm}$ for $B \to \tau\nu$

- $B \to \tau\nu$ could be affected by charged Higgs.



- Example of modifications:

$$\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau) = \mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau)_{\mathrm{SM}} \times r_H$$

where r_H is a modification factor:

$$r_H = \left(1 - \tan^2\beta \, \frac{m_B^2}{m_H^2}\right)^2$$

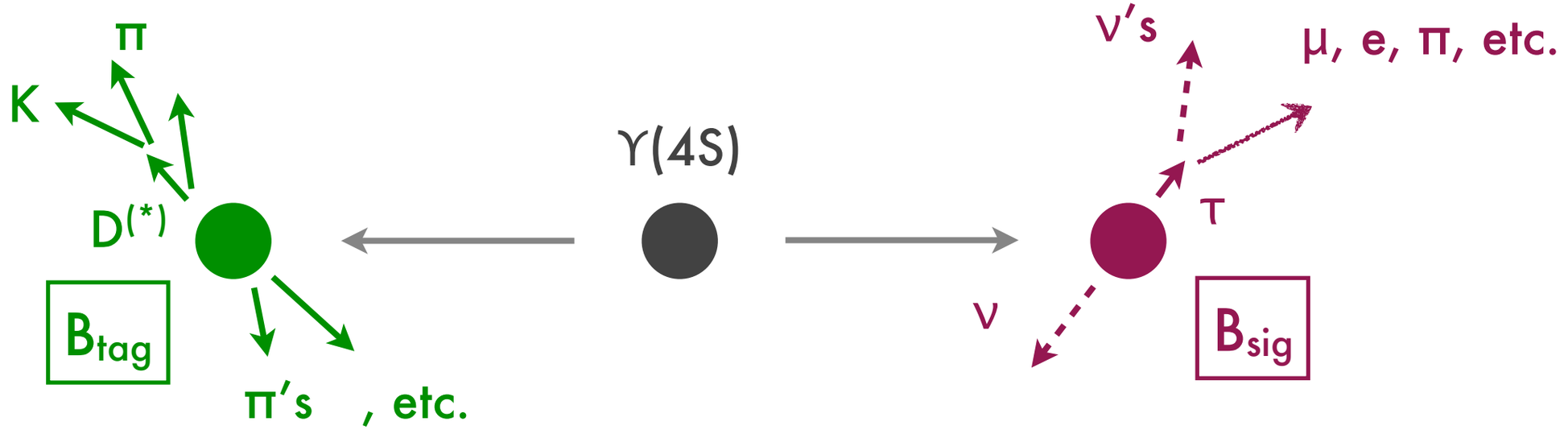
W. S. Hou, Phys. Rev. D 48, 2342 (1993), type II two Higgs doublet model (2HDM).

$$r_H = \left(1 - \frac{\tan^2\beta}{1+\tilde{\epsilon}_0 \tan\beta} \, \frac{m_B^2}{m_H^2}\right)^2$$

A. G. Akeroyd and S. Recksiegel, J. Phys. G 29, 2311 (2003), higher order correction in SUSY models.

Methods for Analyzing $B \to \tau\nu$

Very challenging at hadron colliders due to multiple neutrinos.
At the B factories, we tag one of the B mesons in $e^+e^- \to \Upsilon(4S) \to BB$.



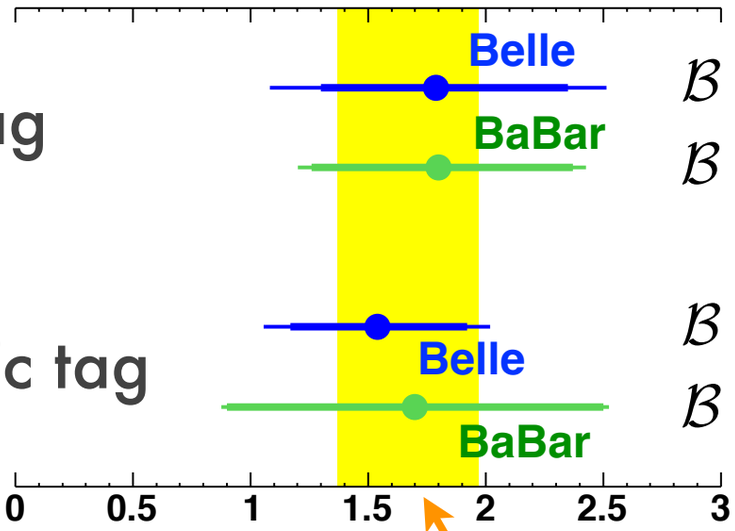
B_{tag} reconstructed from

- hadronic decays $B \to D^{(*)}\pi$, etc.,
- semileptonic decays $B \to D^{(*)}l\nu$.

B_{sig} extracted by using

- extra energy ("E_{ECL}" or "E_{extra}"),
- missing mass squared ("M_{miss}^2").

Status for B→τν before ICHEP 2012



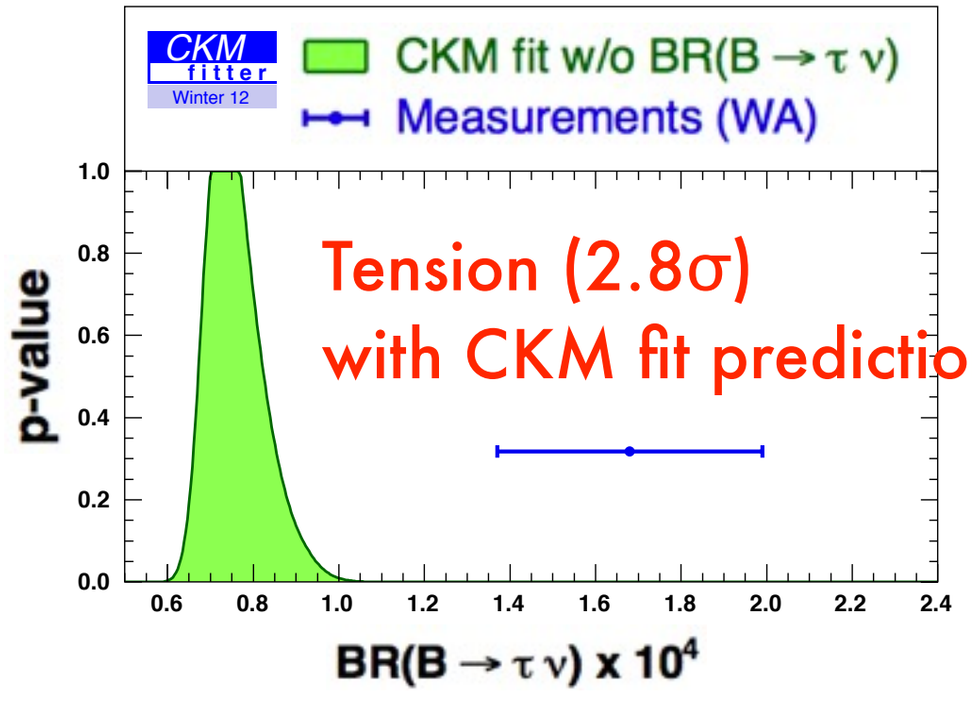
Hadronic tag

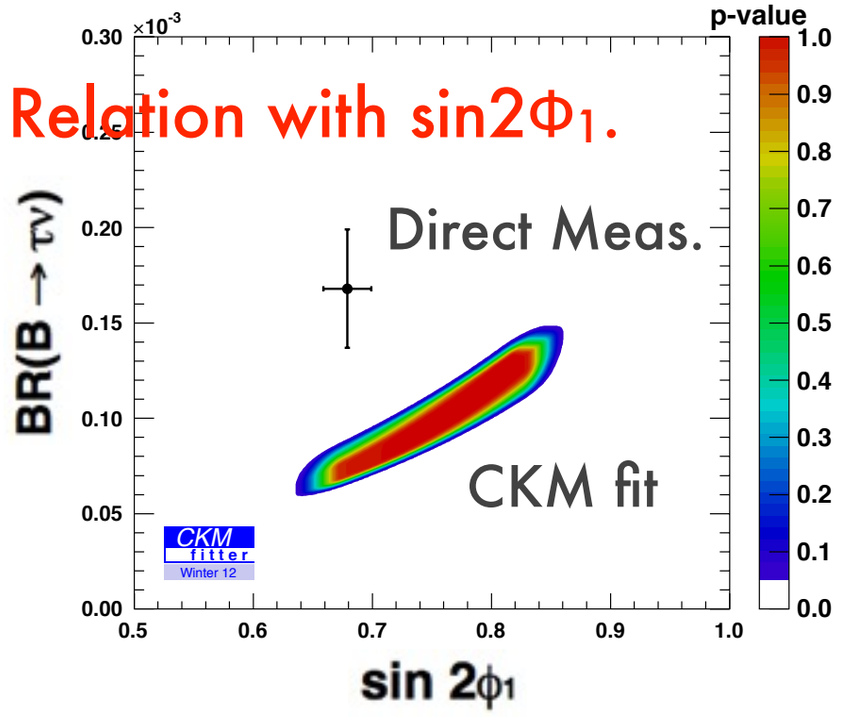
$$\mathcal{B} = [1.79^{+0.56}_{-0.49}(\text{stat})^{+0.46}_{-0.51}(\text{syst})] \times 10^{-4}$$
$$\mathcal{B} = [1.80^{+0.57}_{-0.54}(\text{stat}) \pm 0.26(\text{syst})] \times 10^{-4}$$

Semileptonic tag

$$\mathcal{B} = [1.54^{+0.38}_{-0.37}(\text{stat})^{+0.29}_{-0.31}(\text{syst})] \times 10^{-4}$$
$$\mathcal{B} = [1.7 \pm 0.8(\text{stat}) \pm 0.2(\text{syst})] \times 10^{-4}$$

WA (HFAG): $\mathcal{B}$ = (1.67 ± 0.30) x 10^{-4}

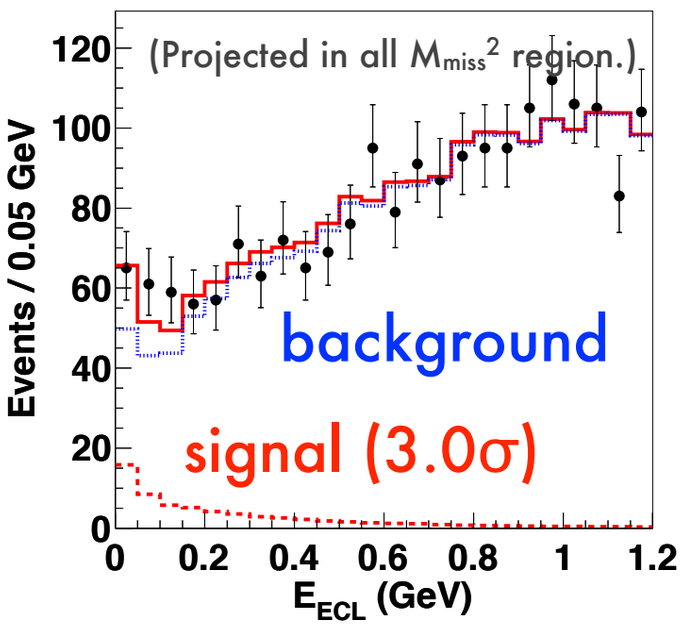


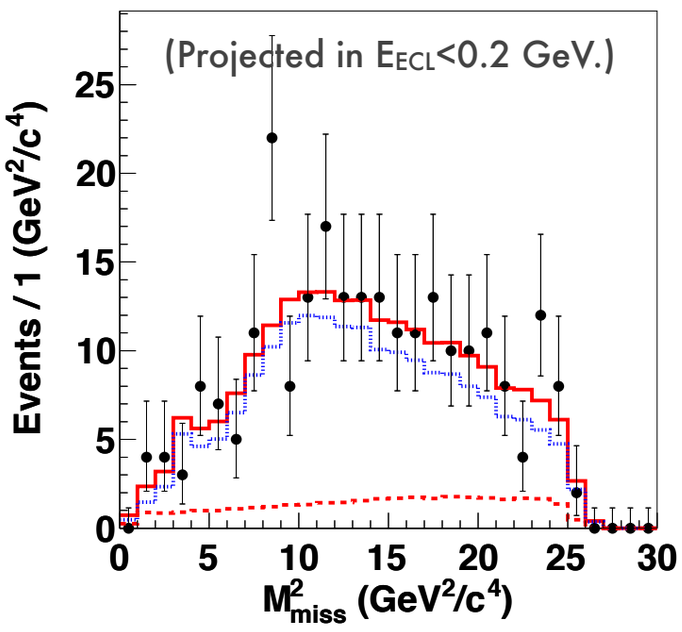


Updates on B→τν at ICHEP 2012

Belle

- PRL 110, 131801 (2013).
- Use 772 M BB (full data) with Had. tag.
- Tag improved, 2-D signal extraction.

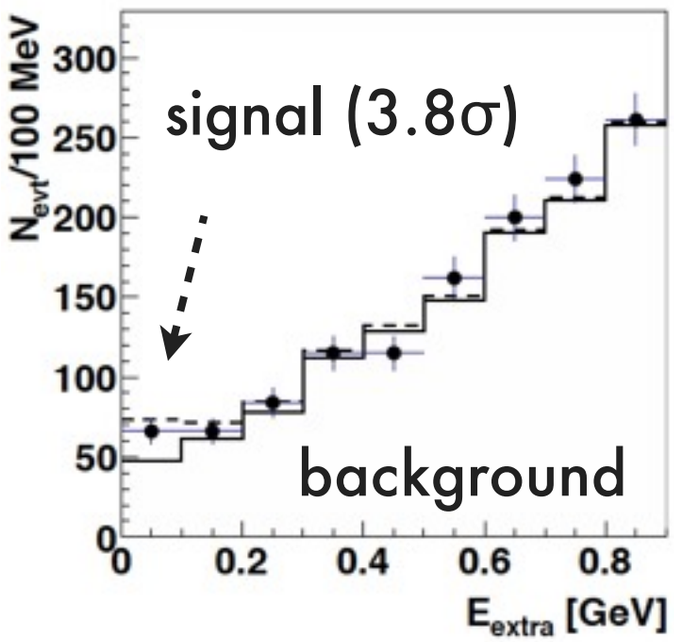




$\mathcal{B}=[0.72^{+0.27}_{-0.25}\pm0.11]\times10^{-4}$.

BaBar

- arXiv:1207.0698 (2012).
- Use 468 M BB (full data) with Had. tag.

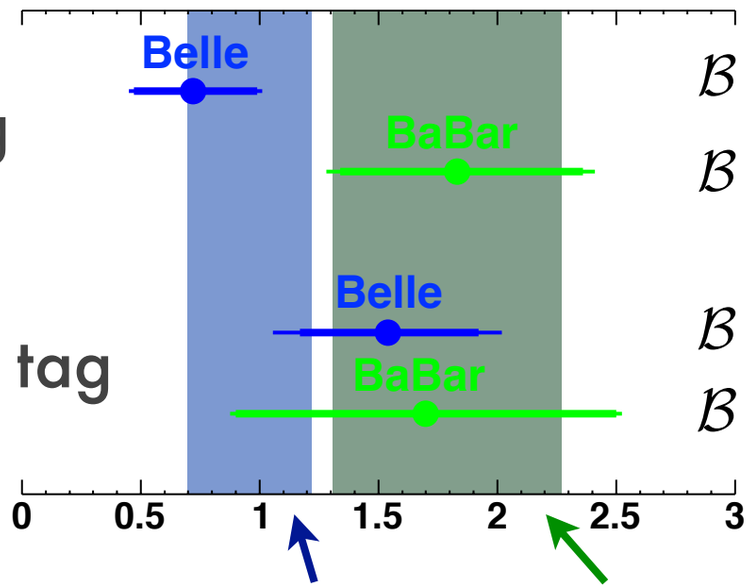


$\mathcal{B}=[1.83^{+0.53}_{-0.49}\pm0.24]\times10^{-4}$.

Status for B→τν after ICHEP 2012

Hadronic tag

Semileptonic tag



$$\mathcal{B} = [0.72^{+0.27}_{-0.25}(\text{stat}) \pm 0.11(\text{syst})] \times 10^{-4}$$

$$\mathcal{B} = [1.83^{+0.53}_{-0.49}(\text{stat}) \pm 0.24(\text{syst})] \times 10^{-4}$$

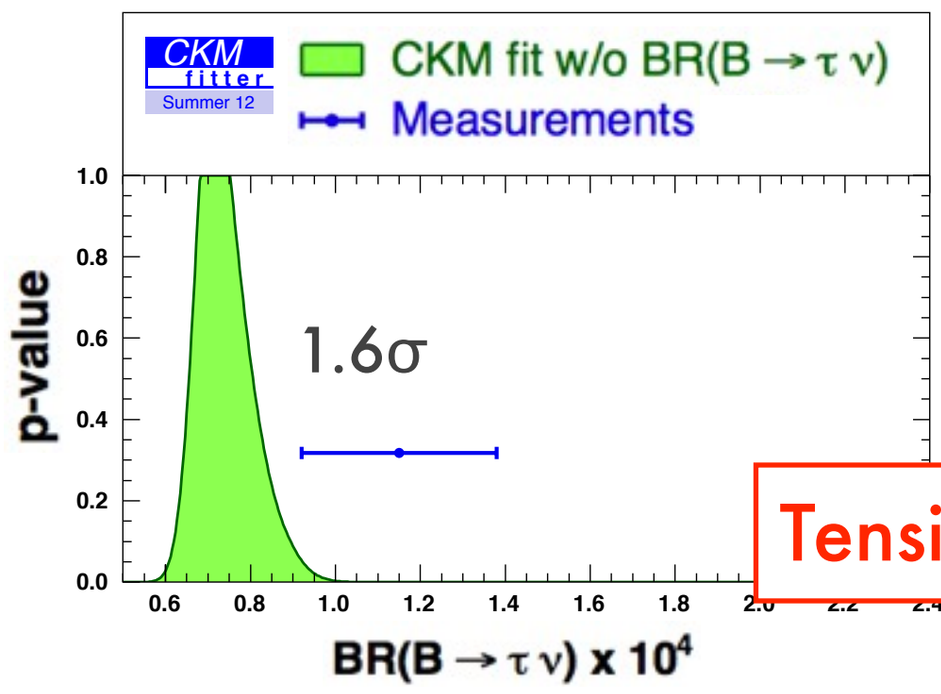
$$\mathcal{B} = [1.54^{+0.38}_{-0.37}(\text{stat})^{+0.29}_{-0.31}(\text{syst})] \times 10^{-4}$$

$$\mathcal{B} = [1.7 \pm 0.8(\text{stat}) \pm 0.2(\text{syst})] \times 10^{-4}$$

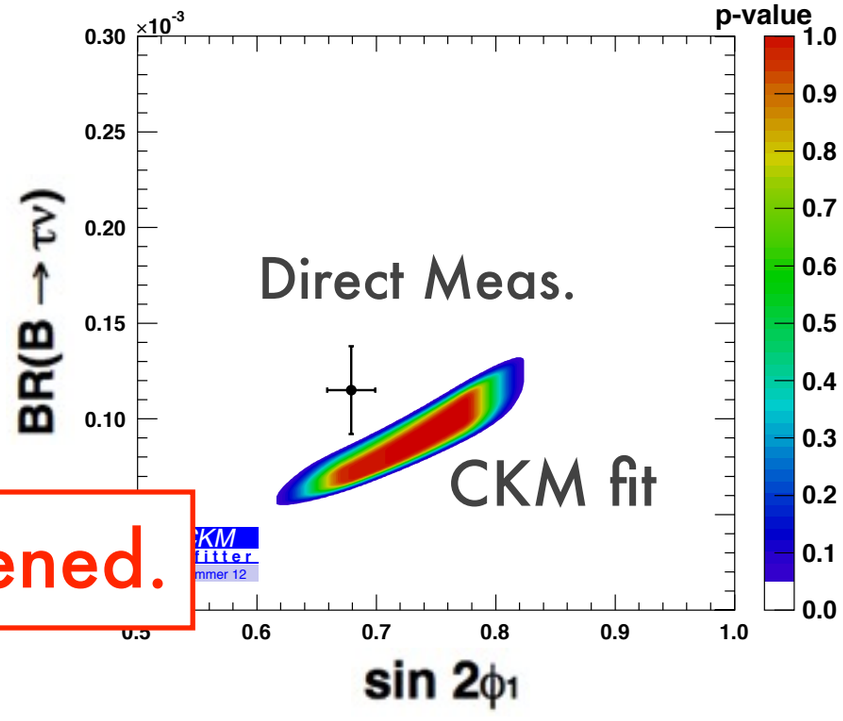
Belle combined: $\mathcal{B}$=(0.96±0.26)x10^{-4}

BaBar combined: $\mathcal{B}$=(1.79±0.48)x10^{-4}

A naive world average: $\mathcal{B}$=(1.15±0.23)x10^{-4}



Tension weakened.



Constraint on Charged Higgs from B→τν

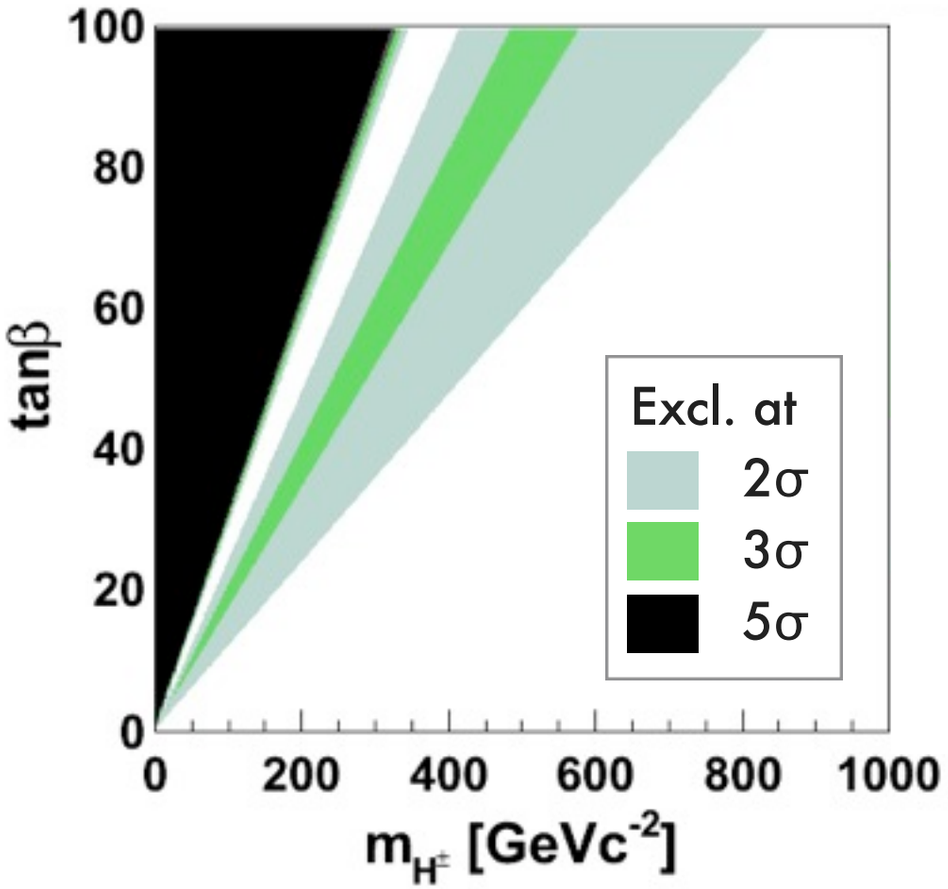
- Assume Type-II 2HDM.

$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{\rm SM} \times r_H$$

$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

- Use
  - $\mathcal{B}(B\to\tau\nu) = (1.15\pm0.23)\times10^{-4}$
  - $\mathcal{B}(B\to\tau\nu)_{SM} = (1.11\pm0.28)\times10^{-4}$

  where $\mathcal{B}(B\to\tau\nu)_{SM}$ is obtained from
  - f_B = (191±9) MeV (HPQCD, PRD86)
  - $|V_{ub}|$ = (4.15±0.49)×10^{-3} (PDG, PRD86)



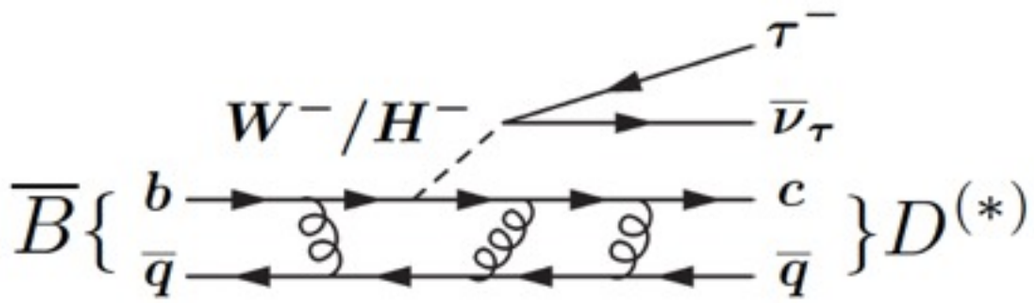
Personal figure by Y. Horii.

Stringent constraint on tanβ and m_H obtained.

Note: constraint strongly depends on f_B and $|V_{ub}|$.

Introduction for $B \to D^{(*)}\tau\nu$

- Could be affected by charged Higgs in extended models.



K. Keirs and A. Soni,
PRD 56, 5786 (1997), ...

- $|V_{cb}|$ and a part of QCD effects canceled by taking ratios.

$$\mathcal{R}(D) = \frac{\mathcal{B}(\overline{B} \to D\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D\ell^-\overline{\nu}_\ell)}, \quad \mathcal{R}(D^*) = \frac{\mathcal{B}(\overline{B} \to D^*\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D^*\ell^-\overline{\nu}_\ell)}$$

$B \to D^{(*)}l\nu$ decays measured precisely, e.g. $\mathcal{B}(B^- \to D^0 l^- \nu)=(2.26\pm0.11)\%$.

- Possible observables additional to the ratios:
  τ polarization, D^* polarization, q^2 distribution, ...

M. Tanaka and R. Watanabe, PRD 87, 034028 (2013), ...

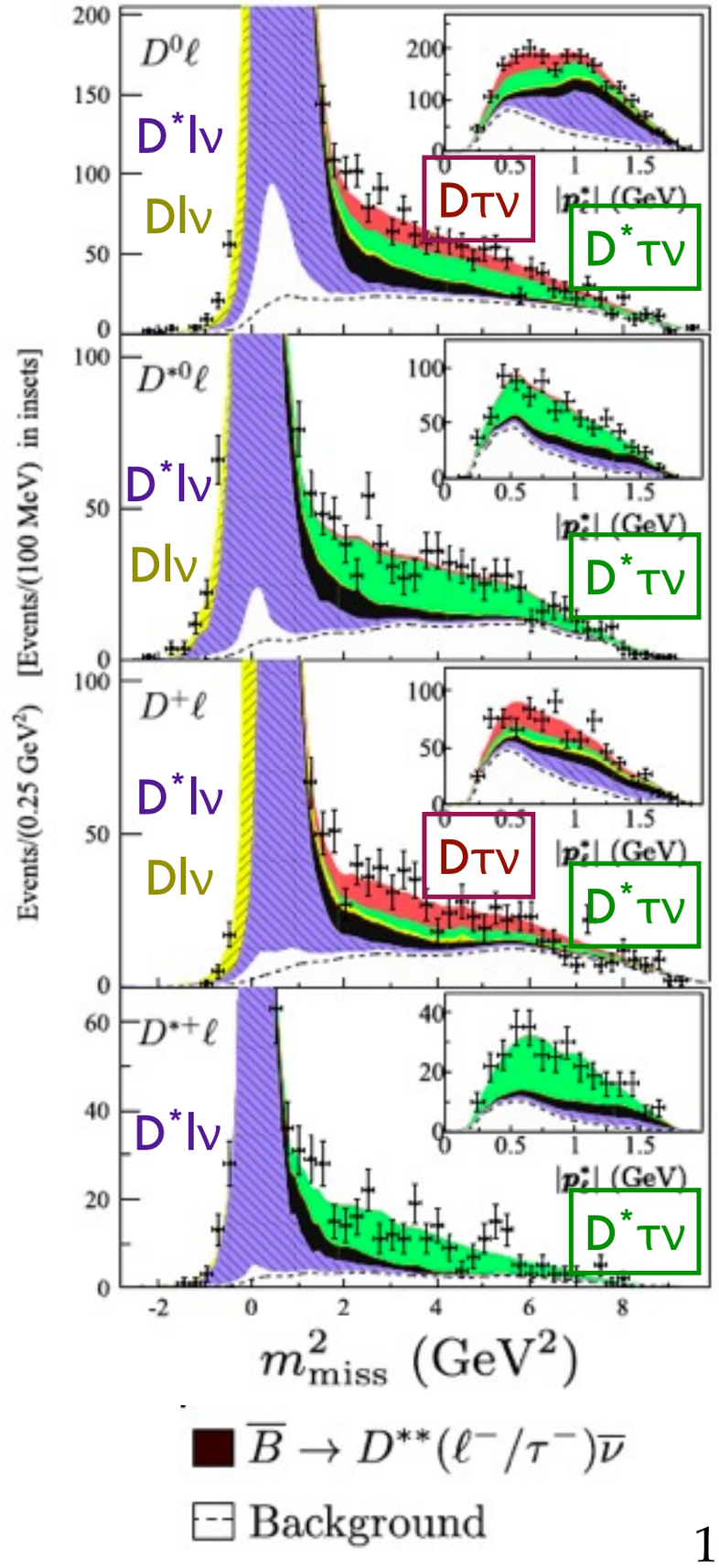
$B \to D^{(*)}\tau\nu$ from BaBar

- PRL 109, 101802 (2012).
- arXiv:1303.0571, submitted to PRD.
- Use *471 M BB* (full data).
- Improved hadronic tag by more modes.
- Boosted decision tree for event selection.

$R(D) = B(D\tau\nu)/B(Dl\nu) = 0.440 \pm 0.058 \pm 0.042$

$R(D^*) = B(D^*\tau\nu)/B(D^*l\nu) = 0.332 \pm 0.024 \pm 0.018$

Systematic uncertainties from
D^{**} BG, BG PDFs, BG yields, etc.



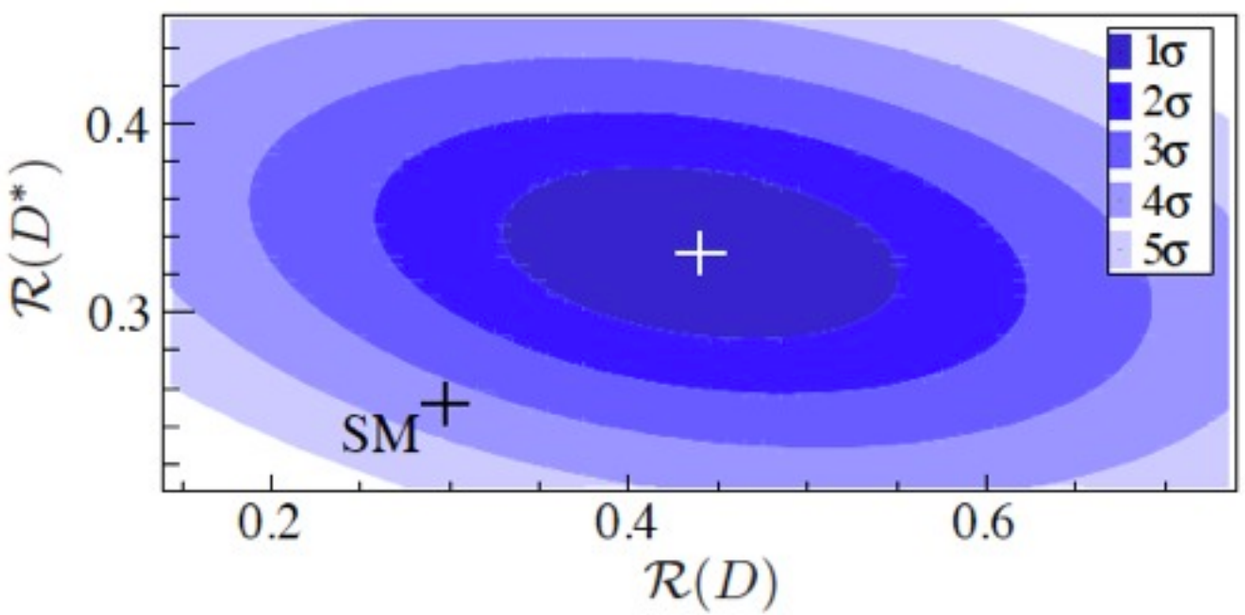
$B \to D^{(*)}\tau\nu$ from BaBar and SM

$$\mathcal{R}(D)_{\rm exp} = 0.440 \pm 0.072 \qquad \mathcal{R}(D^*)_{\rm exp} = 0.332 \pm 0.030$$

$\updownarrow$ 2.0σ $\qquad$ $\updownarrow$ 2.7σ

$$\mathcal{R}(D)_{\rm SM} = 0.297 \pm 0.017 \qquad \mathcal{R}(D^*)_{\rm SM} = 0.252 \pm 0.003$$

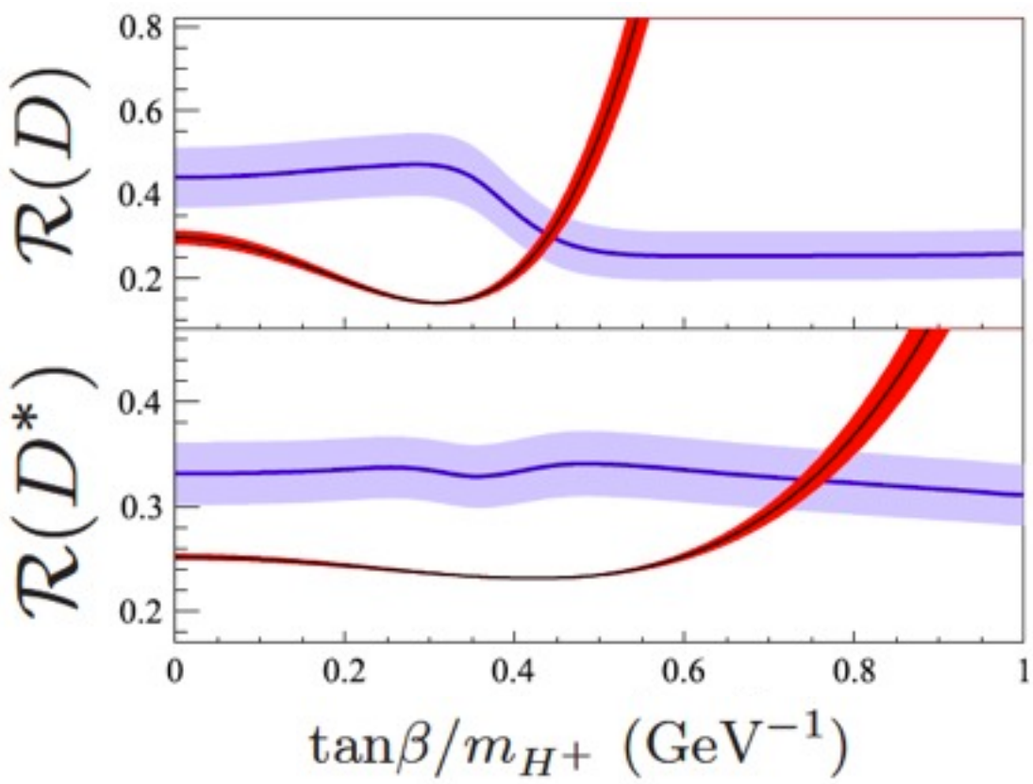
SM expectations in S. Fajfer, J. Kamenik, I. Nisandzic, PRD 85, 094025 (2012).



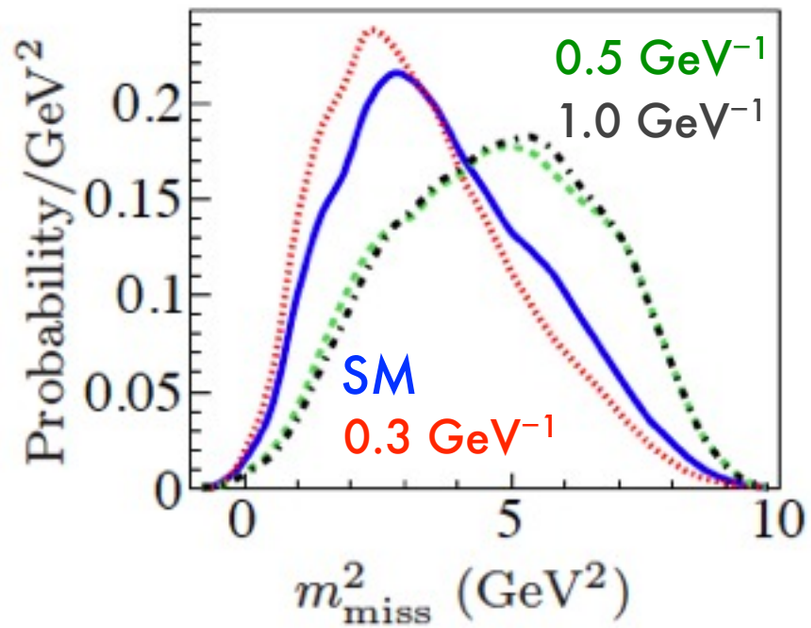
The possibility that the measured R(D) and R(D*) both agree with the SM predictions is excluded at the 3.4σ level.

(σ for 1-D Gaussian function)

$B \to D^{(*)} \tau \nu$ from BaBar and Type-II 2HDM

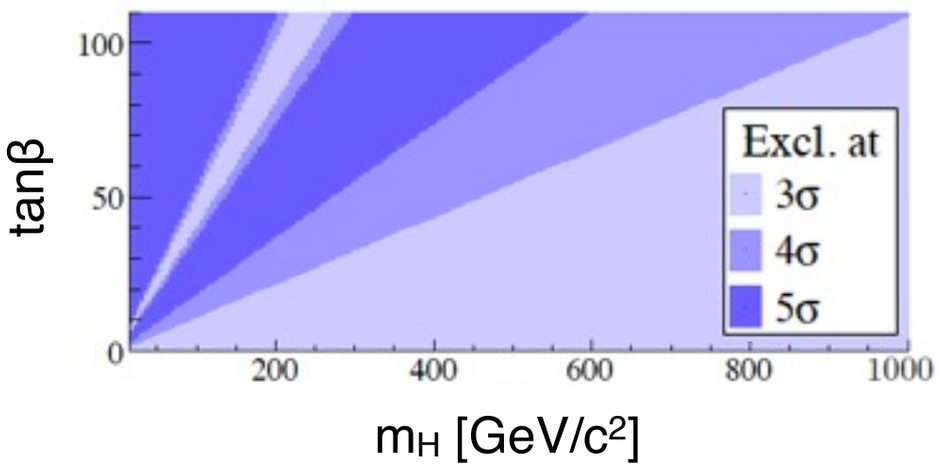


Blue: this result, red: Type-II 2HDM.



(The values indicated for $\tan\beta/m_H$.)

Exp. $R(D^{(*)})$ dependency mainly from m_{miss}^2 dependency (reflection of q^2 dependency).



The combination of R(D) and R(D*) excludes the Type-II 2HDM at 99.8% C.L. for any value of $\tan\beta/m_H$.

Note: Type III and q^2 spectra in arXiv:1303.0571.

$B \to D^{(*)} \tau \nu$ from Belle

A. Bozek's averages shown at KEK-FF 2013:

(naive averages for inclusive and exclusive hadronic tags)

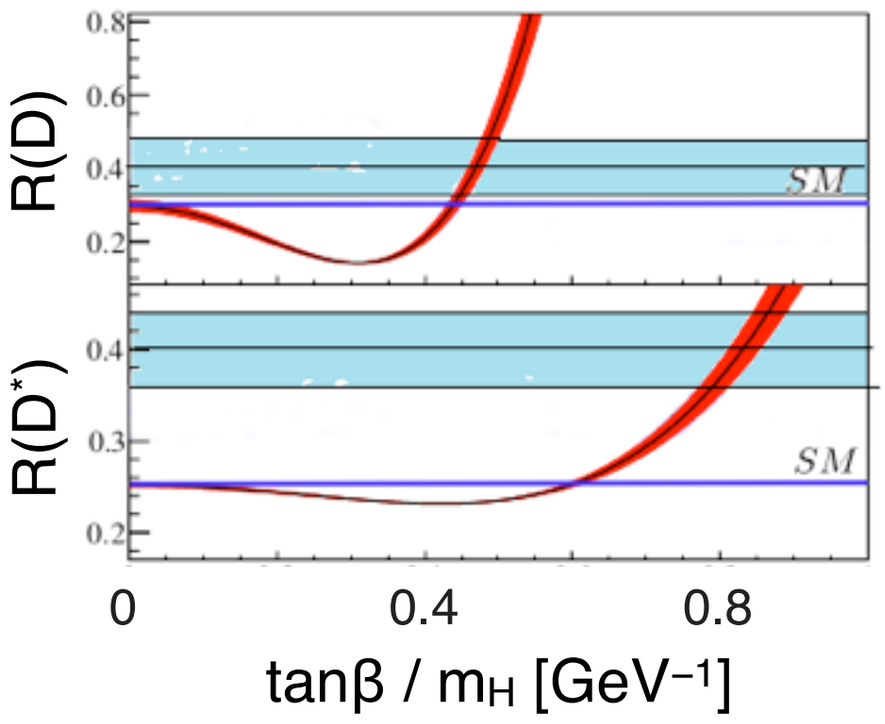
$R(D) = 0.430 \pm 0.091$
$R(D^*) = 0.405 \pm 0.047$

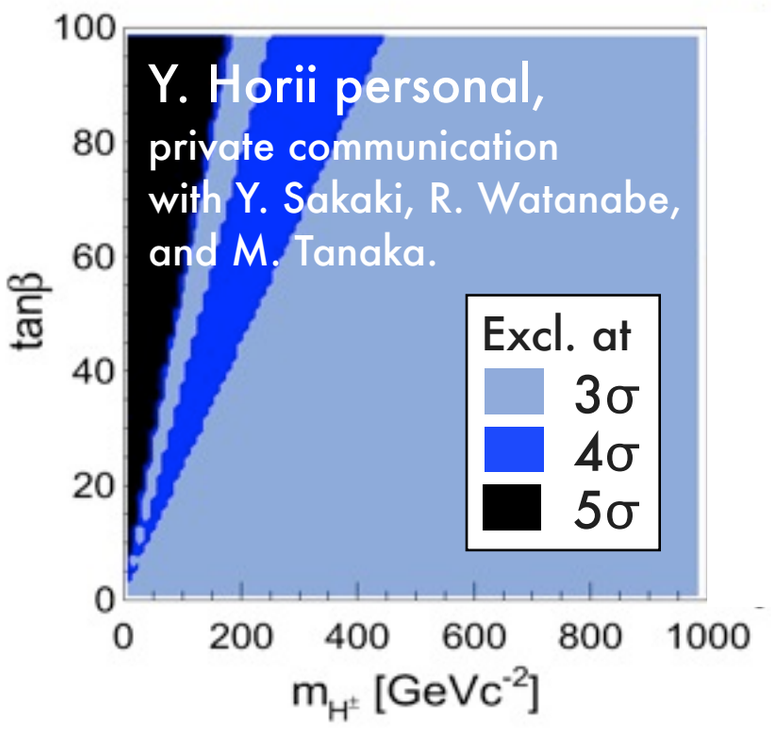
PRL 99 (2007) (535×10^6)
PRD 82 (2010) (657×10^6)
hep-ex/0910.4301 (657×10^6)

SM deviations:
R(D): 1.4σ
$R(D^*)$: 3.0σ
Combined: 3.3σ

Correlation btw R(D) and $R(D^*)$ neglected conservatively.

Constraint on Type-II 2HDM:

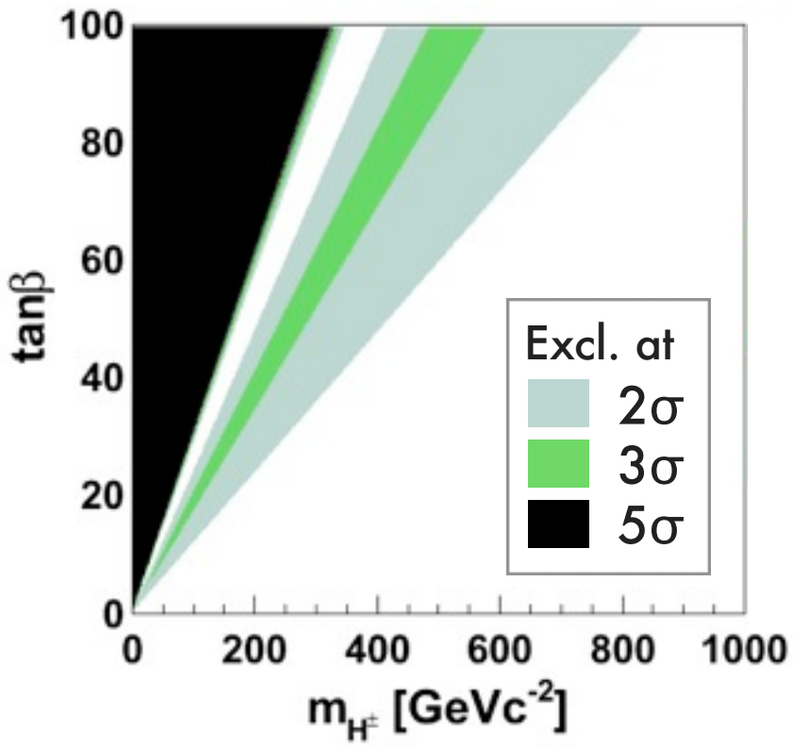




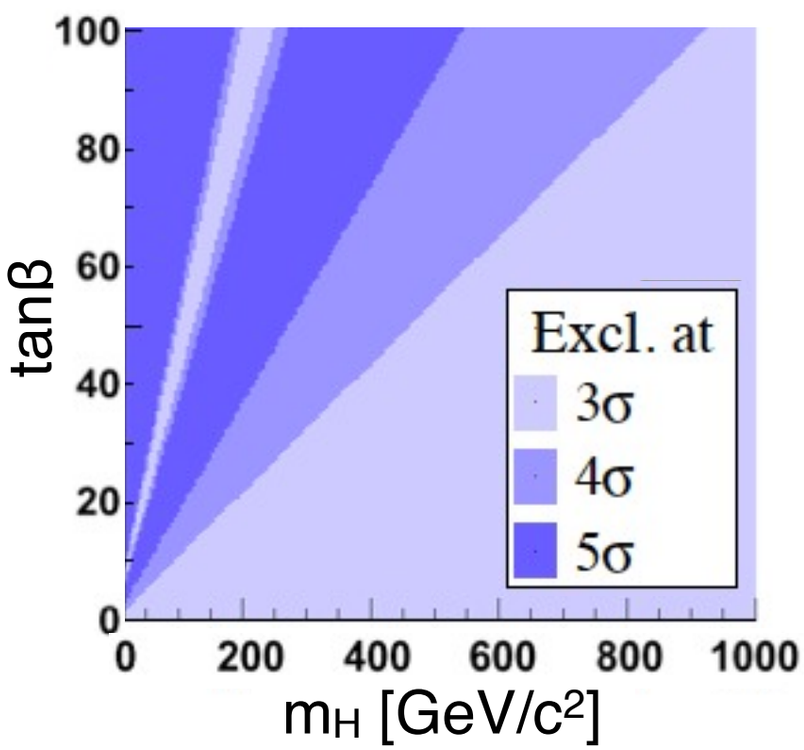
Experimental $R(D^{(*)})$ dependence on $\tan\beta/m_H$ not considered.
Experimental correlation between R(D) and $R(D^*)$ not considered.

Comparison for $B \to \tau\nu$ and $B \to D^{(*)}\tau\nu$ Results

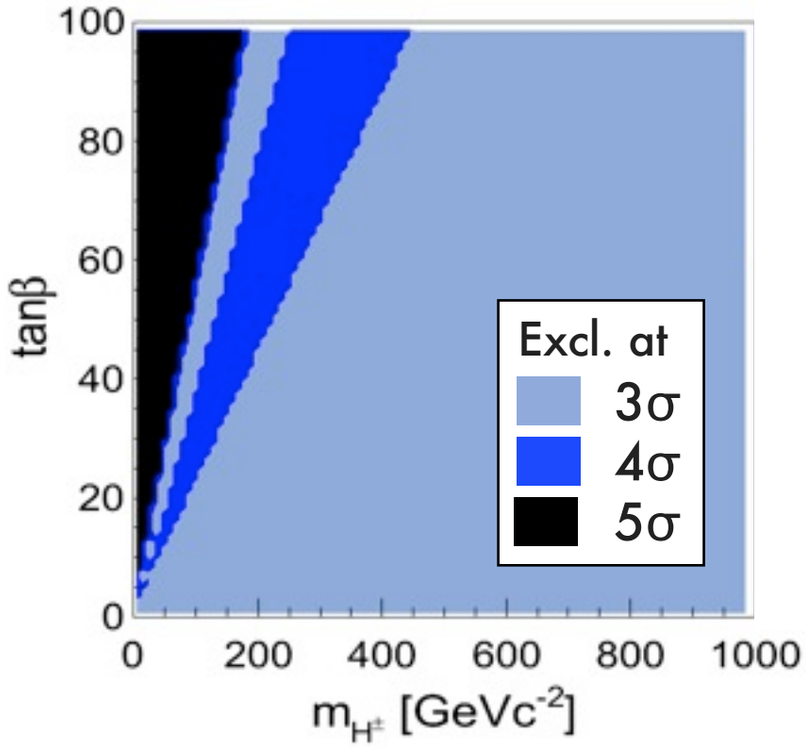
$B \to \tau\nu$, Belle+BaBar
(using naive average)



$B \to D^{(*)}\tau\nu$, BaBar
(incl. corr, $\tan\beta/m_H$ effect)



$B \to D^{(*)}\tau\nu$, Belle
(naive average by A. Bozek)
(w/o corr, $\tan\beta/m_H$ effect)



- Local minimum at about $\tan\beta/m_H = 0.5$ [GeV^{-1}c^2] for $B \to D^{(*)}\tau\nu$ excluded by $B \to \tau\nu$ by >5σ.
- Stronger constraint may be obtained by combining all results.
- Should be careful: strong dependency on central values, correlations, …

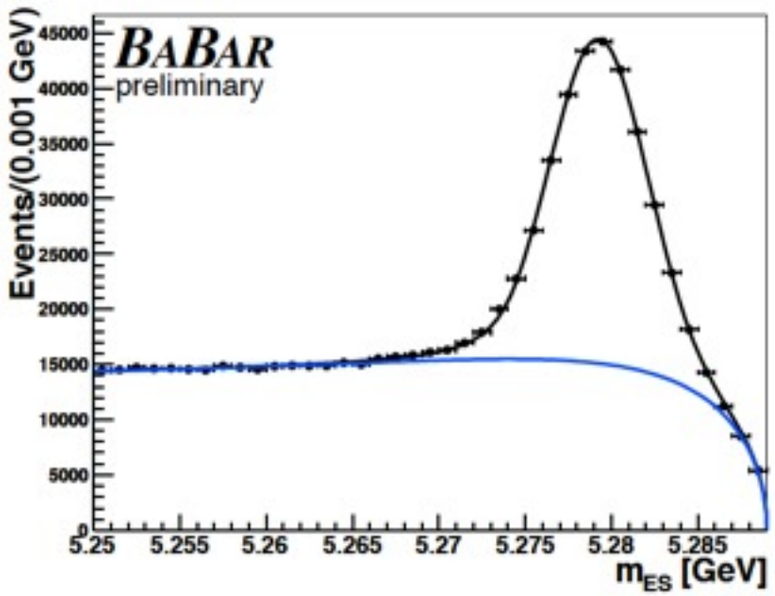
Summary

- $B \to \tau\nu$ and $B \to D^{(*)}\tau\nu$ interesting for a test of SM and a search for new physics.
- Recent $B \to \tau\nu$ results weaken the tension against CKM fit.
- Recent $B \to D^{(*)}\tau\nu$ results disfavor SM and type-II two Higgs doublet model by a level of $>3\sigma$.
  - Final result from Belle using full data coming soon.
- Important to improve the precision at Belle II.

Backup slides

Tag for B→τν

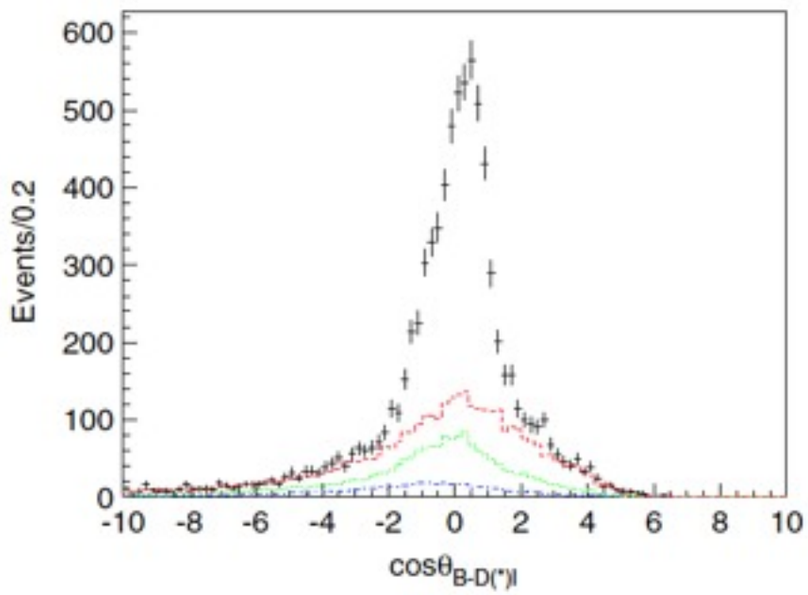
Hadronic tag for B→τν by BaBar



$$m_{\mathrm{ES}} = \sqrt{s/4 - p_B^2}$$

- Modes: $B \to D^{(*)}\pi$, etc.
- Efficiency = ~0.2%.
- Less background.
- p_{Bsig} determined.

Semileptonic tag for B→τν by Belle



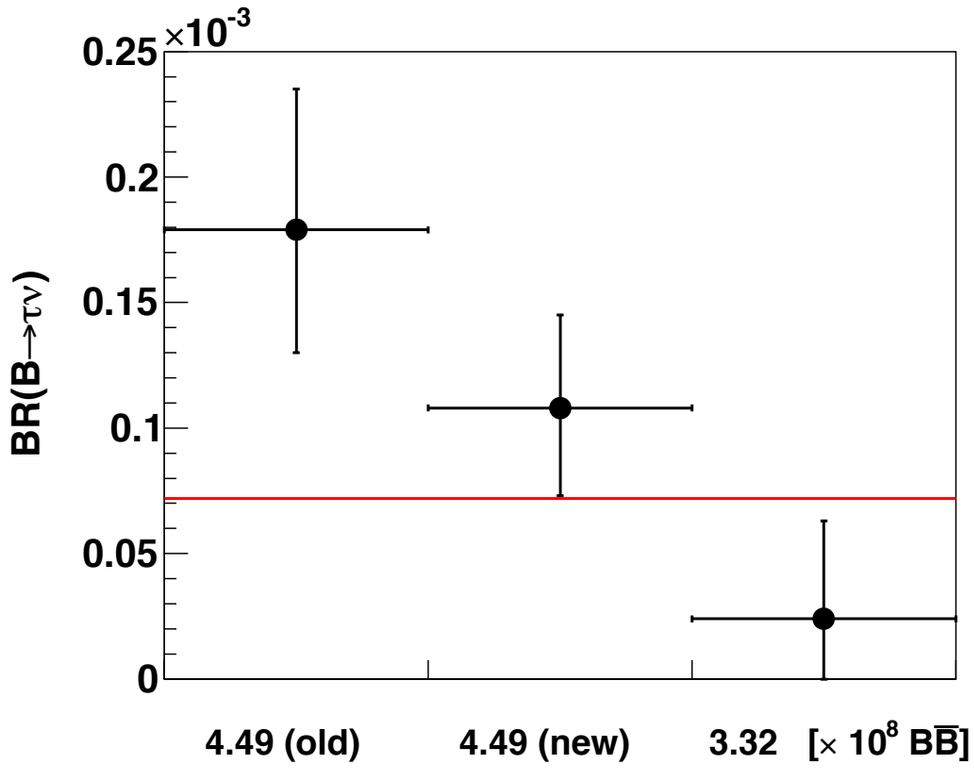
$$\cos\theta_{B,D^{(*)}\ell} = \frac{2E_{\mathrm{beam}}^{\mathrm{cms}} E_{D^{(*)}\ell}^{\mathrm{cms}} - m_B^2 - M_{D^{(*)}\ell}^2}{2P_B^{\mathrm{cms}} \cdot P_{D^{(*)}\ell}^{\mathrm{cms}}}$$

- Modes: $B \to D^{(*)}l\nu$.
- Efficiency = ~1%.
- More background.
- p_{Bsig} not determined.

Comparison for B→τν Using Hadronic Tag at Belle

	PRL 97 (2006)	This analysis	
Tag	Hadronic tag	Hadronic tag (new)	
Number of $B\overline{B}$ events ($\times 10^8$)	4.49	4.49	3.22
Efficiency ($\times 10^{-4}$)	3.0	11.2	11.2
Signal yield	$24.1^{+7.6}_{-6.6}$	$54.1^{+18.8}_{-17.4}$	$8.6^{+14.0}_{-12.4}$
$\mathcal{B}(B^- \to \tau^- \overline{\nu}_\tau)$ ($\times 10^{-4}$)	$1.79^{+0.56}_{-0.49}$	$1.08^{+0.37}_{-0.35}$	$0.24^{+0.39}_{-0.34}$

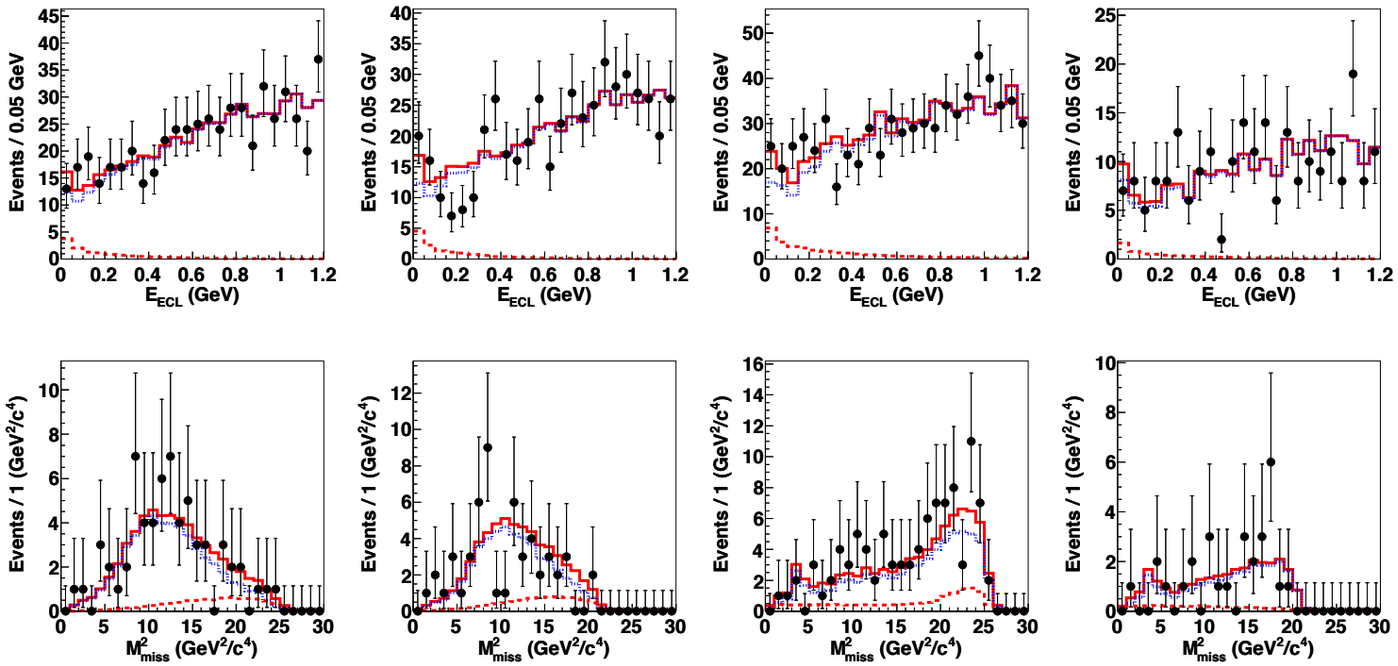
- New analysis is based on improved tag, loose event selection, and reprocessed data.
- Most of the data after the selection are independent from old analysis.
- Assuming that all events in old analysis are included in new analysis, the remaining data sample in $N_{BB} = 4.49 \times 10^8$ provides BR ~ $(0.6 \pm 0.4) \times 10^{-4}$ (1.9σ from old result).



B→τν by Hadronic Tag at Belle, Mode Independence

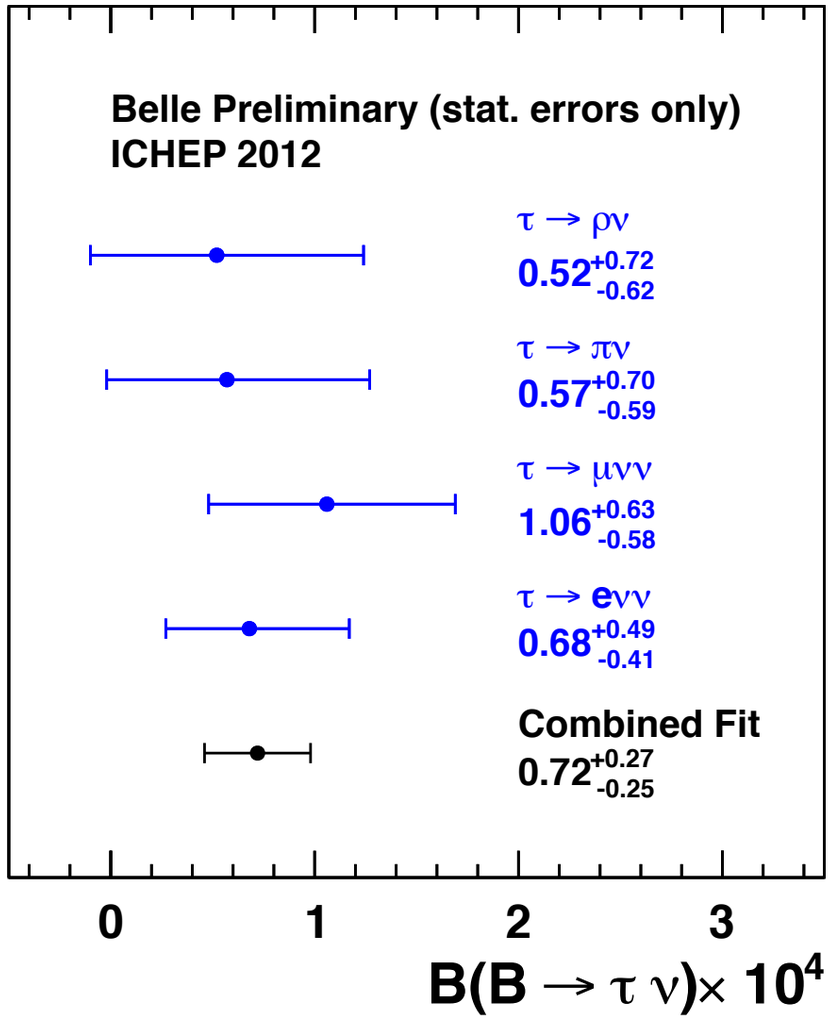
As a check, we fit by floating the yields for different τ modes.

τ→eνν τ→μνν τ→πν τ→ρν



Take τ→eνν, μνν, ρν cross-feeds in τ→πν candidates as signal.

Mode	Number of signal	Efficiency
$e^-\overline{\nu}_e\nu_\tau$	$15.5^{+11.2}_{-9.4}$	2.98×10^{-4}
$\mu^-\overline{\nu}_\mu\nu_\tau$	$25.6^{+15.1}_{-13.8}$	3.12×10^{-4}
$\pi^-\nu_\tau$	$7.8^{+9.5}_{-7.9}$	1.76×10^{-4}
$\rho^-\nu_\tau$	$13.6^{+18.7}_{-16.1}$	3.37×10^{-4}



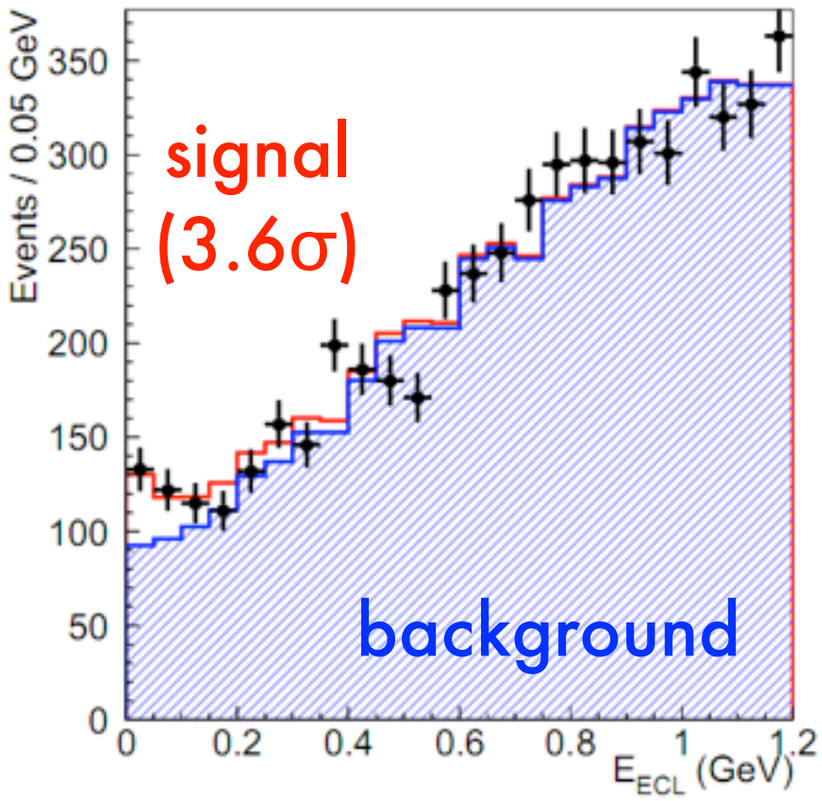
Consistent results.

Rare unobserved BG decays (e.g. B→μνγ) would show up in individual signal modes.

B→τν by Semileptonic Tag

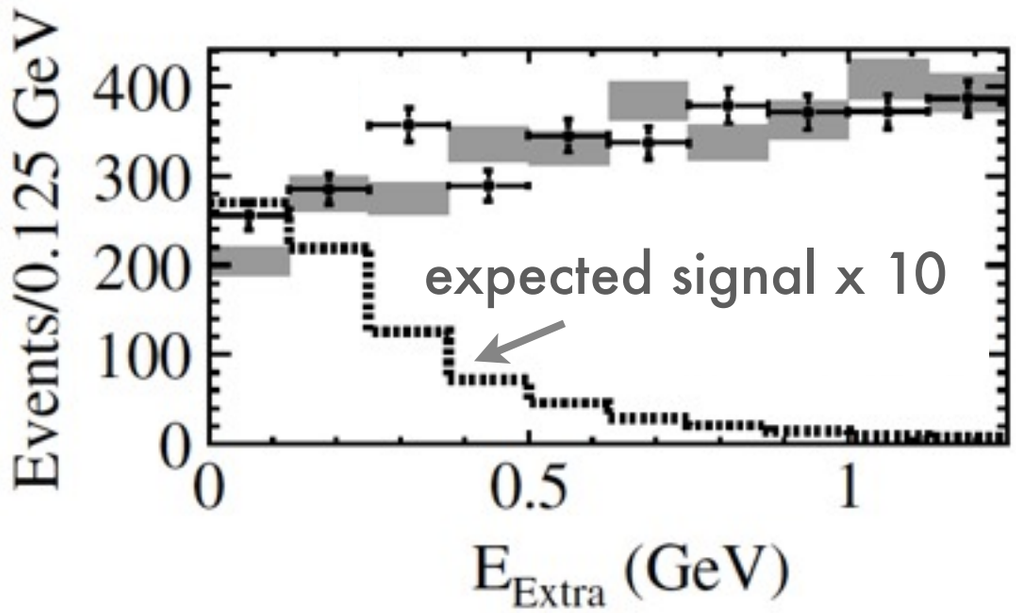
Belle

- PRD 82, 071101(R) (2010).
- Use 657 M BB.
- $B=[1.54^{+0.38}_{-0.37}{}^{+0.29}_{-0.31}]\times10^{-4}$.



BaBar

- PRD 81, 051101(R) (2010).
- Use 459 M BB.
- $B=[1.7\pm0.8\pm0.2]\times10^{-4}$.

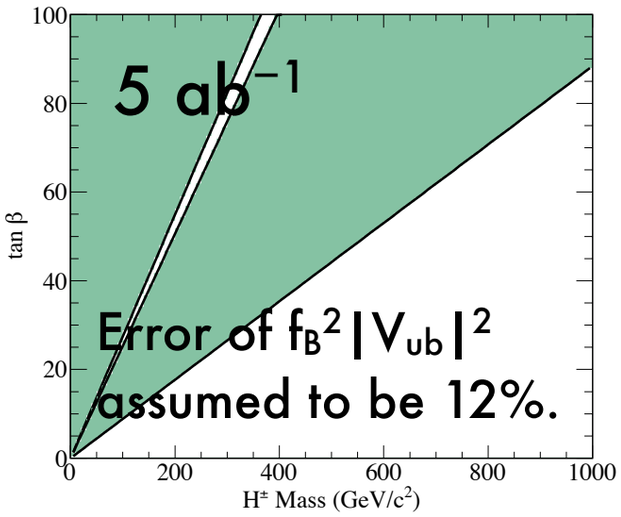


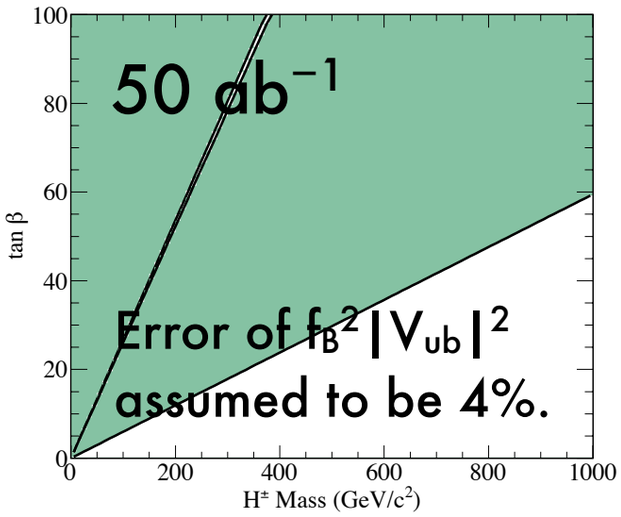
(Counting method employed.)

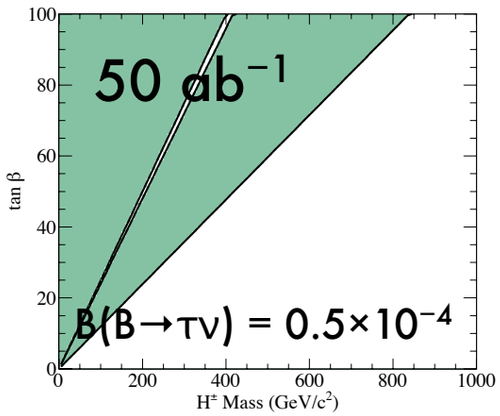
Prospects for Belle II (√ Luminosity Assumption)

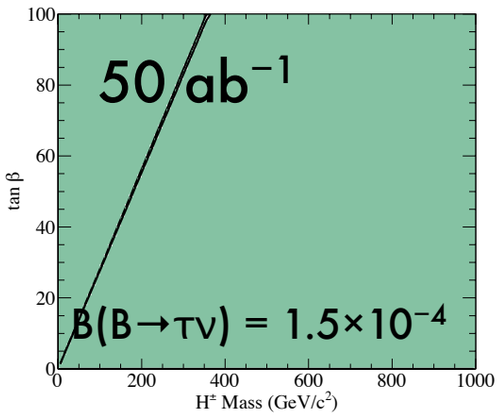
$B \to \tau\nu$

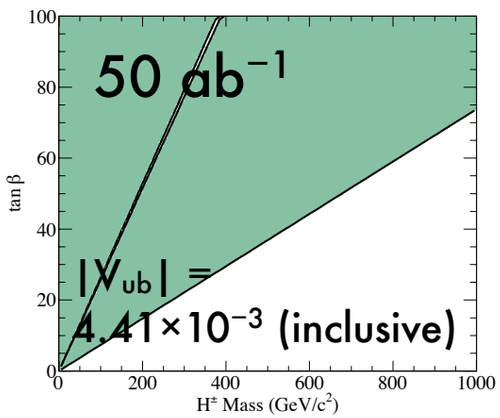
- Expected sensitivity: a few % at 50 ab^{-1}.
- For Type-II 2HDM, we show expected exclusion region at 95% C.L.:

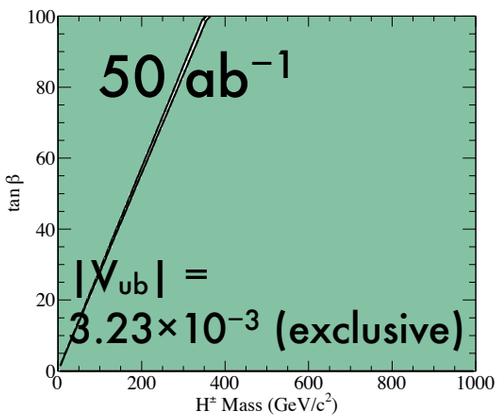












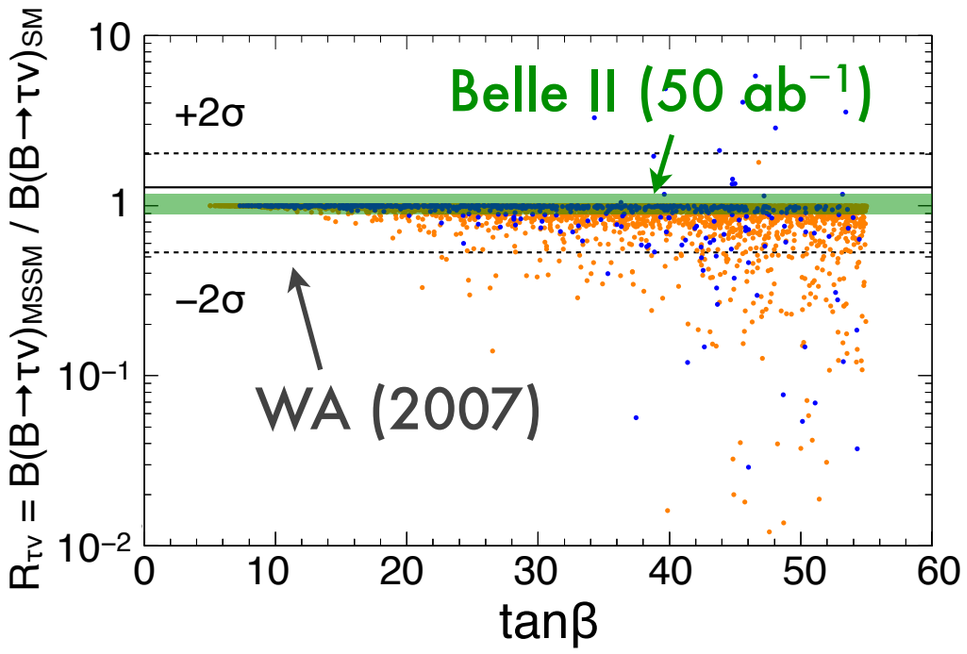
- Central values of $B(B \to \tau\nu) = 1\times10^{-4}$, f_B = 190 MeV, and $|V_{ub}| = 4.15\times10^{-3}$ are assumed.
- Relative error of $f_B^2|V_{ub}|^2$ assumed to be comparable to the one of measured $B(B \to \tau\nu)$.

Strong dependence on central values of $B(B \to \tau\nu)$ and $|V_{ub}|$.

Prospects for Belle II (√ Luminosity Assumption)

B→τν

- Assuming 2-parameter nonuniversal Higgs model, we expect



H. Baer, V. Barger, and A. Mustafayev, PRD85, 075010

μ>0, m_h = 125±1 GeV, m_t = 173.3 GeV

blue: m_0 < 5 TeV, orange: m_0 < 20 TeV

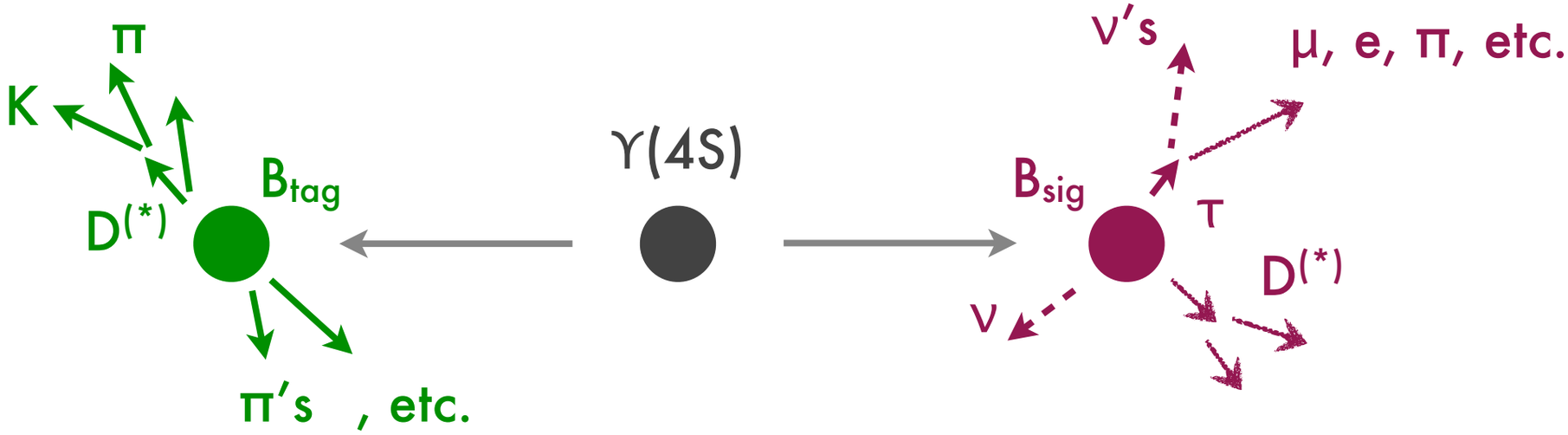
B→μν, eν

- 5σ observation expected for $B(B\to\mu\nu)_{SM}$ at ~10 ab^{-1}.
- $\mathcal{O}(10^{-8})$ sensitivity at 50 ab^{-1}.

Interesting to compare with B→τν.

Methods for Analyzing $B \to D^{(*)}\tau\nu$

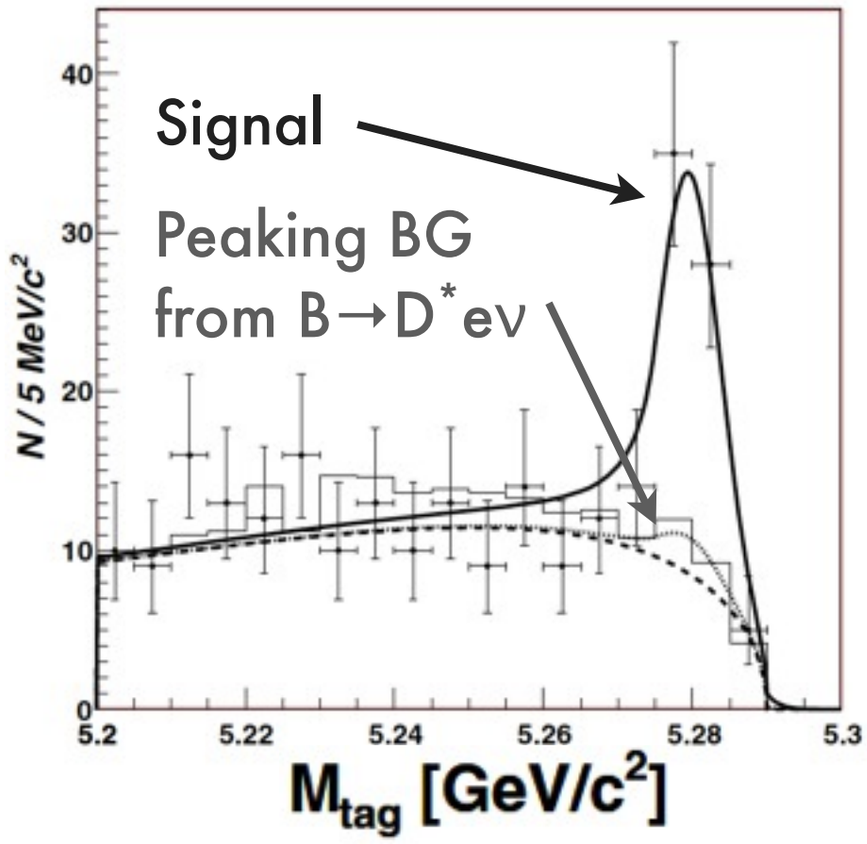
Exploit that a B meson pair is generated by $e^+e^- \to \Upsilon(4S) \to BB$.



- Hadronic tag: reconstruct B_{tag} in hadronic decays $B \to D^{(*)}\pi$, etc., and detect signal using remaining particles (similarly to $B \to \tau\nu$).
- Inclusive tag: detect signal decay products excluding neutrinos, and reconstruct B_{tag} using invariant mass for remaining particles M_{tag}.

$\bar{B}^0 \to D^* \tau \nu$ by Inclusive Tag from Belle

- PRL 99, 191807 (2007).
- Use 535 M BB.
- First observation of signal (5.2σ).



$$\mathcal{B}(D^{*+}\tau^-\bar{\nu}_\tau) = [2.02^{+0.40}_{-0.37}(\text{stat}) \pm 0.37(\text{syst})]\%$$

Syst. from tag efficiency, sig efficiency, etc.

Largest, estimated from control sample $B^0 \to D^{*-}\pi^+$.

Consistent with SM value (1.41±0.07)% [C.-H. Chen and C.-Q. Geng, JHEP10, 053 (2006)].

$B^{\pm} \to D^{(*)}\tau\nu$ by Hadronic Tag from Belle

- Using 657 M BB.
- Simultaneous fit to both subsets.
- $D^{(*)}l\nu$ as control sample and normalization.
- Evidence for signals.

$$R(D^0\tau^-\bar{\nu}_\tau/D^0l^-\bar{\nu}_\tau) = 0.70^{+0.19}_{-0.18}(\text{stat})^{+0.11}_{-0.09}(\text{syst})$$

3.8σ

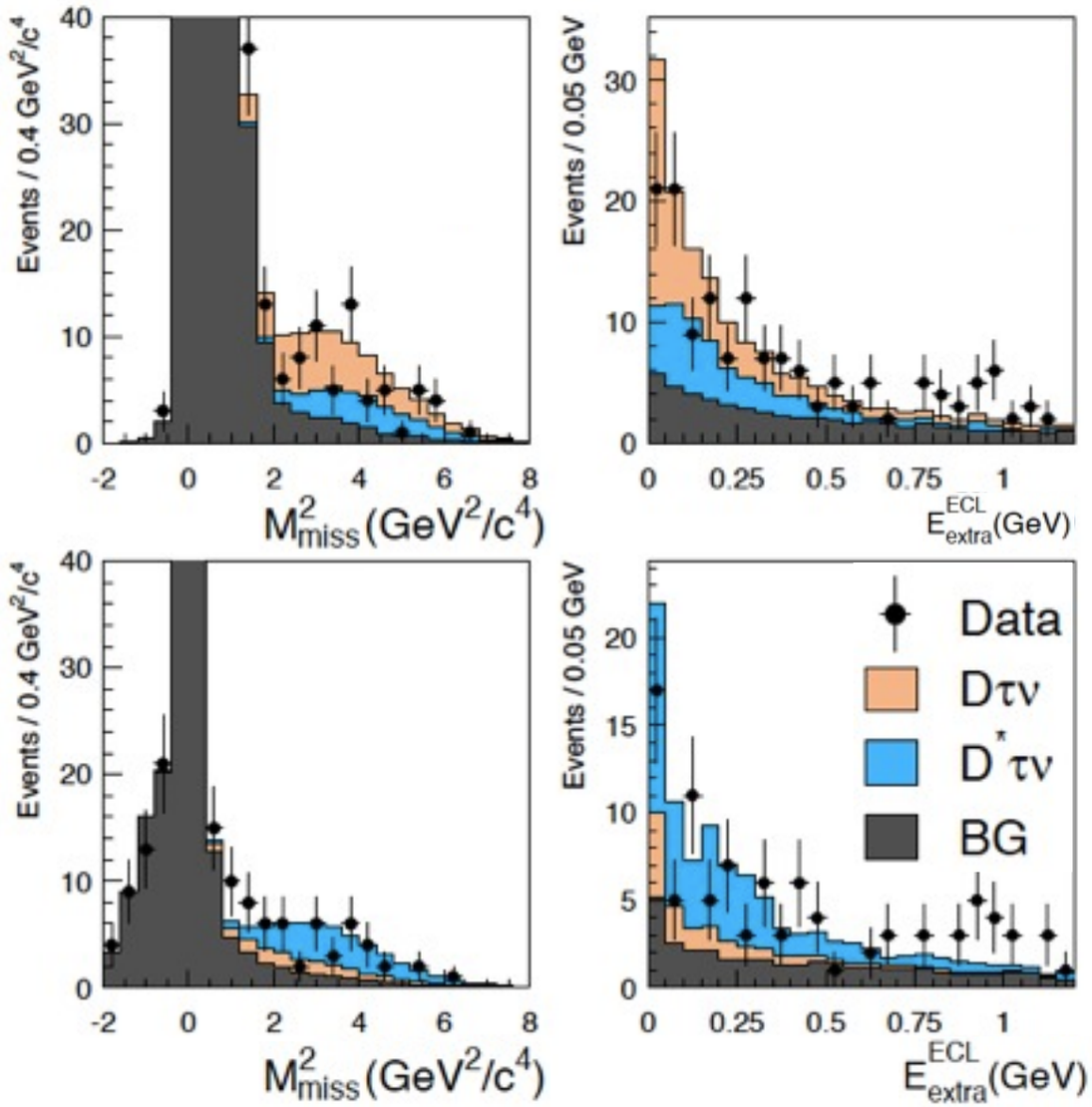
$$R(D^{*0}\tau^-\bar{\nu}_\tau/D^{*0}l^-\bar{\nu}_\tau) = 0.47^{+0.11}_{-0.10}(\text{stat})^{+0.06}_{-0.07}(\text{syst})$$

3.9σ

$$\mathcal{B}(D^0\tau^-\bar{\nu}_\tau) = [1.51^{+0.41}_{-0.39}(\text{stat})^{+0.24}_{-0.19}(\text{syst}) \pm 0.15(\text{norm})]\%$$

$$\mathcal{B}(D^{*0}\tau^-\bar{\nu}_\tau) = [3.04^{+0.69}_{-0.66}(\text{stat})^{+0.40}_{-0.47}(\text{syst}) \pm 0.22(\text{norm})]\%$$

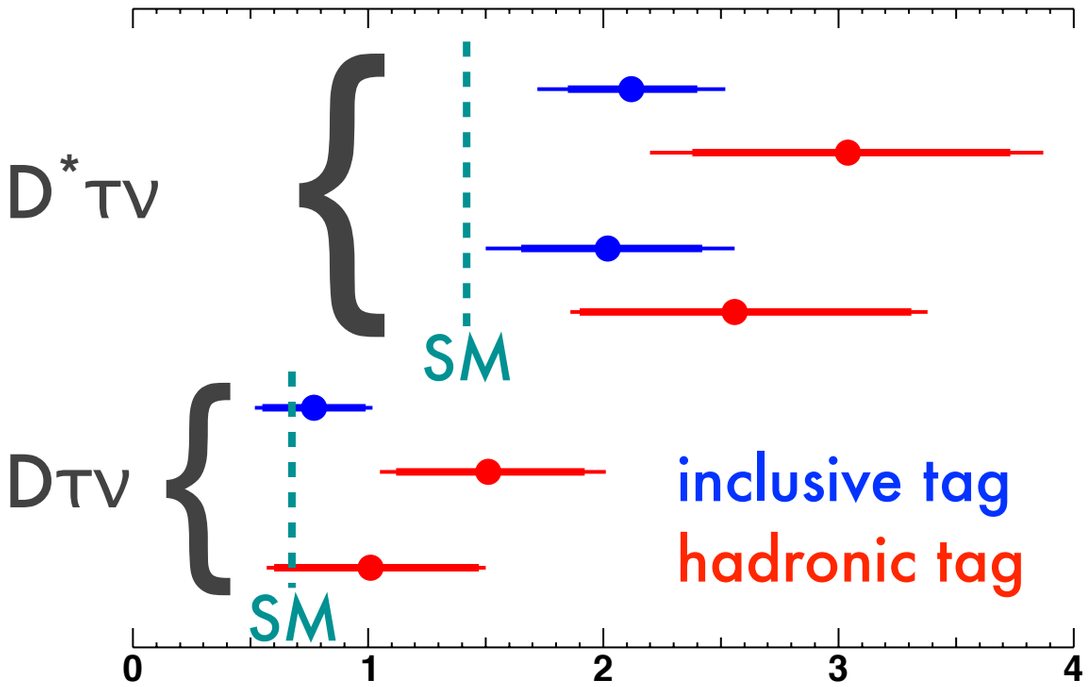
Syst. from PDFs and cross-feeds.



BG: Dlν, D*lν, D**lν, DX, ...

arXiv:0910.4301

Summary for $B \to D^{(*)}\tau\nu$ from Belle



$\mathcal{B}(D^{*0}\tau^-\bar{\nu}_\tau) = [2.12^{+0.28}_{-0.27}(\text{stat}) \pm 0.29(\text{syst})]\%$

$\mathcal{B}(D^{*0}\tau^-\bar{\nu}_\tau) = [3.04^{+0.69}_{-0.66}(\text{stat})^{+0.40}_{-0.47}(\text{syst}) \pm 0.22(\text{norm})]\%$

$\mathcal{B}(D^{*+}\tau^-\bar{\nu}_\tau) = [2.02^{+0.40}_{-0.37}(\text{stat}) \pm 0.37(\text{syst})]\%$

$\mathcal{B}(D^{*+}\tau^-\bar{\nu}_\tau) = [2.56^{+0.75}_{-0.66}(\text{stat})^{+0.31}_{-0.22}(\text{syst}) \pm 0.10(\text{norm})]\%$

$\mathcal{B}(D^{0}\tau^-\bar{\nu}_\tau) = [0.77 \pm 0.22(\text{stat}) \pm 0.12(\text{syst})]\%$

$\mathcal{B}(D^{0}\tau^-\bar{\nu}_\tau) = [1.51^{+0.41}_{-0.39}(\text{stat})^{+0.24}_{-0.19}(\text{syst}) \pm 0.15(\text{norm})]\%$

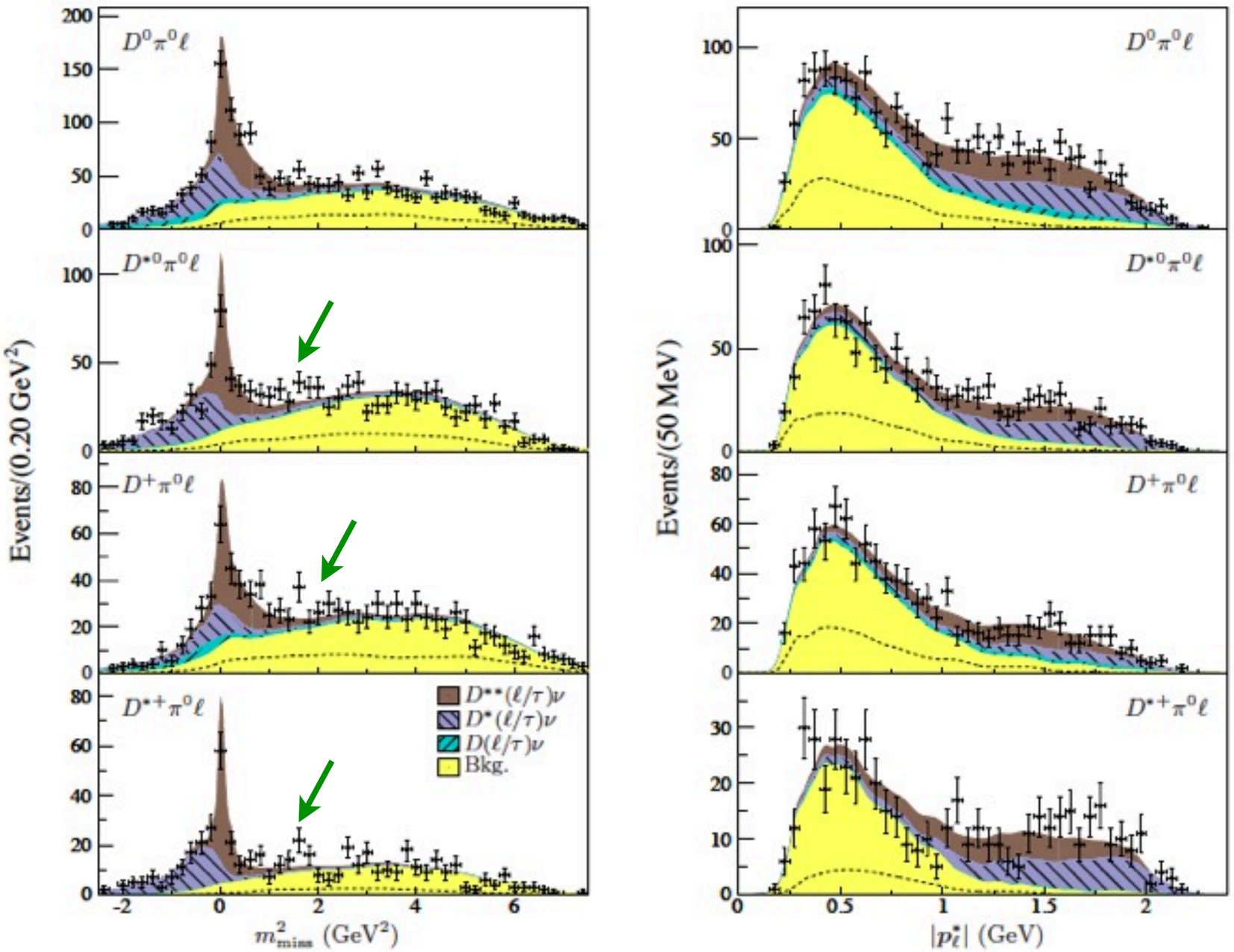
$\mathcal{B}(D^{+}\tau^-\bar{\nu}_\tau) = [1.01^{+0.46}_{-0.41}(\text{stat})^{+0.13}_{-0.11}(\text{syst}) \pm 0.10(\text{norm})]\%$

inclusive tag: PRL 99 (535M BB), PRD 82 (657M BB).
hadronic tag: arXiv:0910.4301 (657M BB).

- Good agreement btw the results for inclusive and hadronic tags.
- Not significant but slightly larger than SM expectations.

D^{**} Background for $D^{(*)}\tau\nu$ at BaBar

Simultaneous fit for signal candidates and $D\pi^0 l$ control sample.

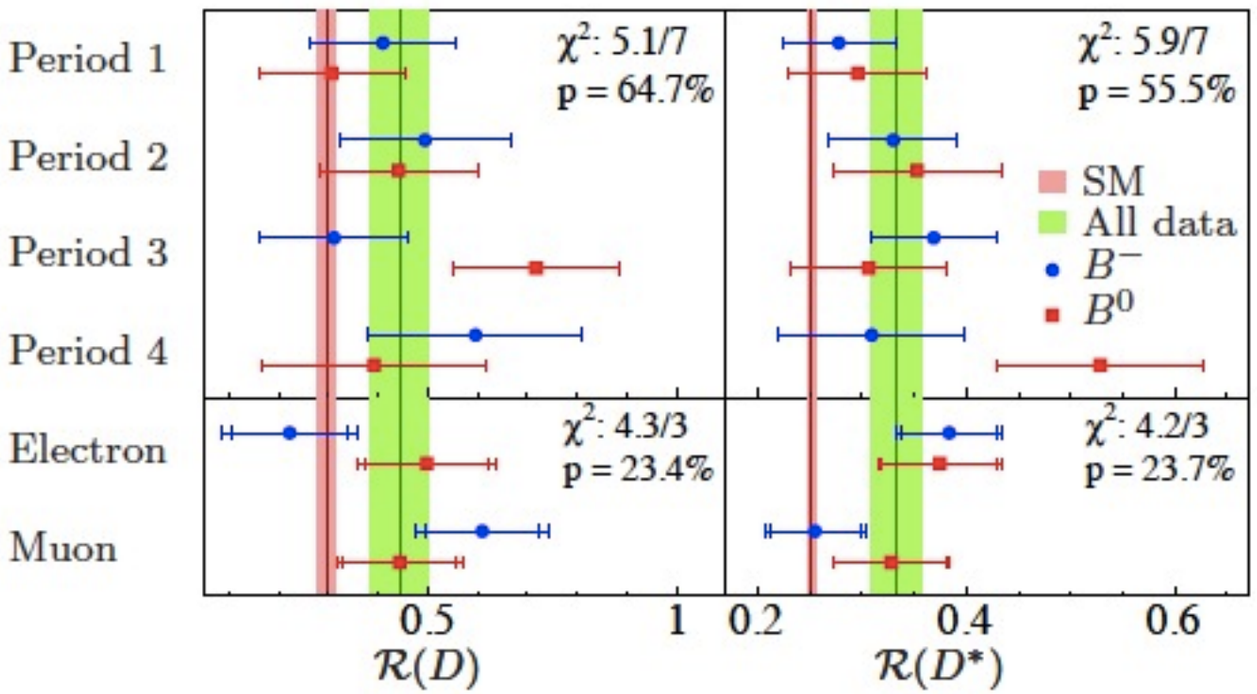


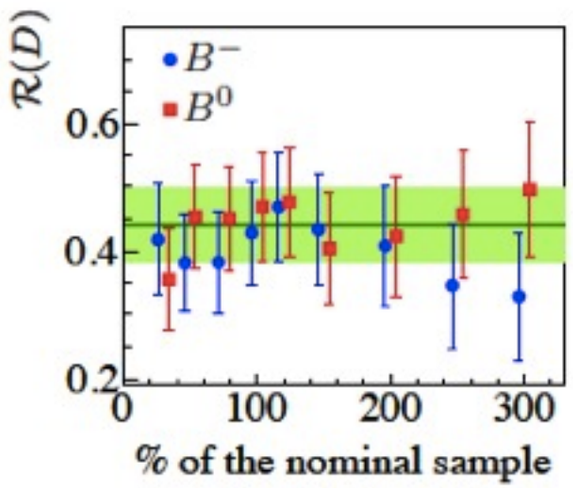
Effect of small enhancement in higher region taken in Syst.

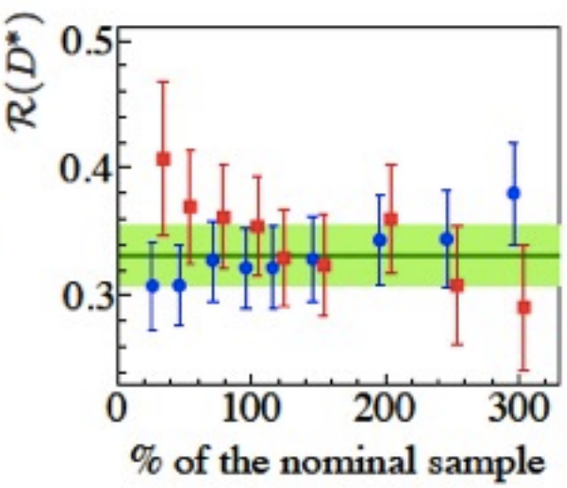
Examples of Various Checks for $B \to D^{(*)}\tau\nu$ from BaBar

Run periods, lepton modes

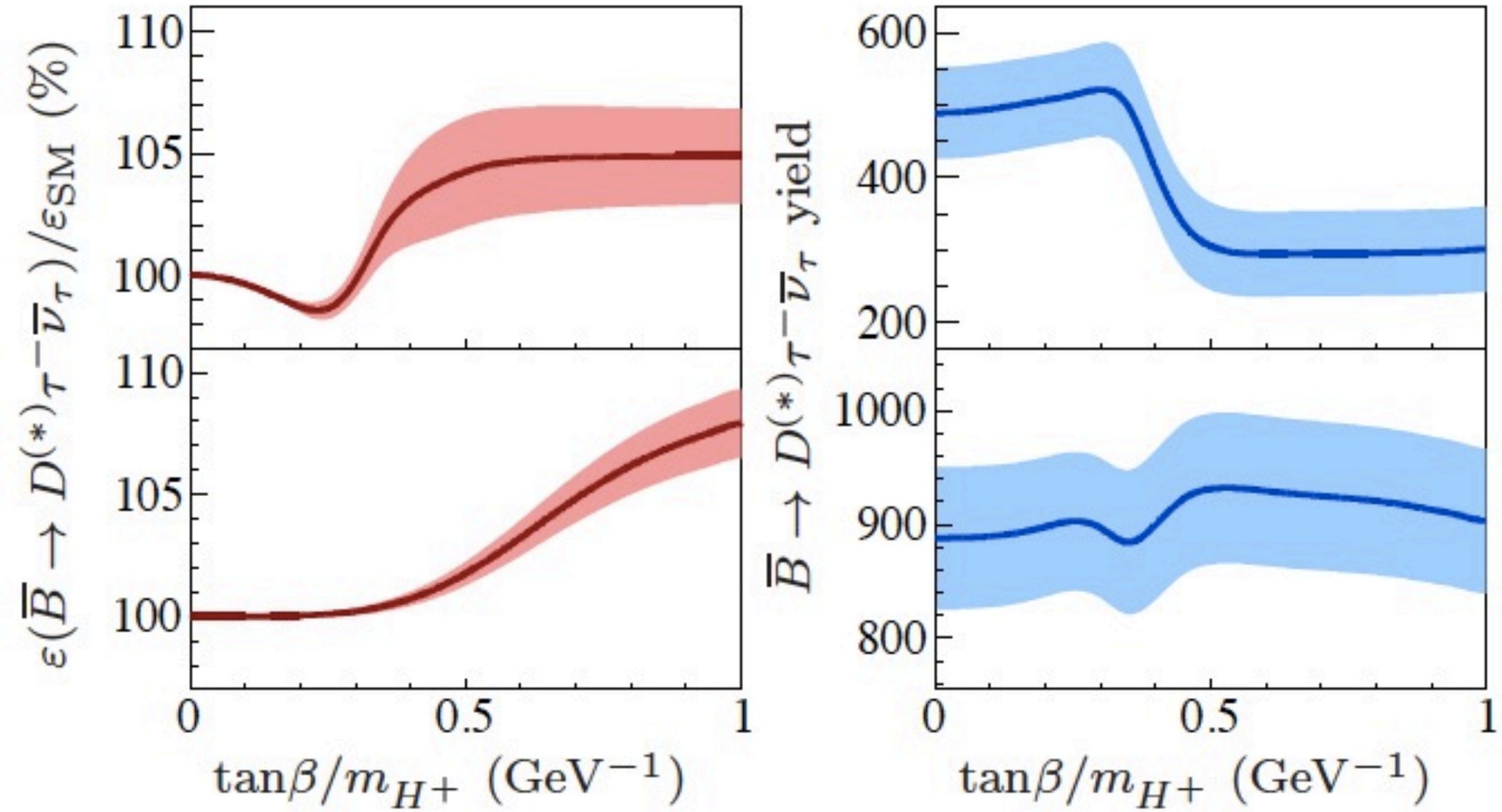
BDT requirements







Dependence on $\tan\beta/m_H$ for $B\to D^{(*)}\tau\nu$ from BaBar



Constraint on Type III 2HDM from $B \to D^{(*)}\tau\nu$ by BaBar