

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

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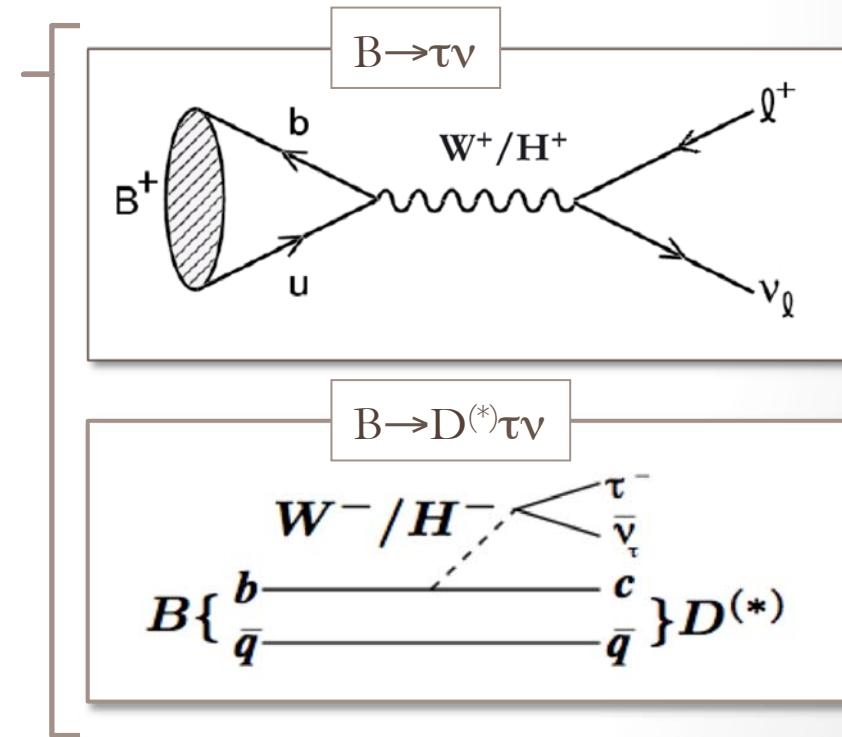
9<sup>th</sup> Franco-Italian meeting on B physics  
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18-19 February, 2013

# Outline

- Indirect  $H^\pm$  searches at B factories
- Analysis features and data sample
- $B \rightarrow D^{(*)} \tau \nu$  results
- $B \rightarrow \tau \nu$  results
- Combined constraints on type II 2-Higgs-Doublet Model
- Conclusions and perspectives

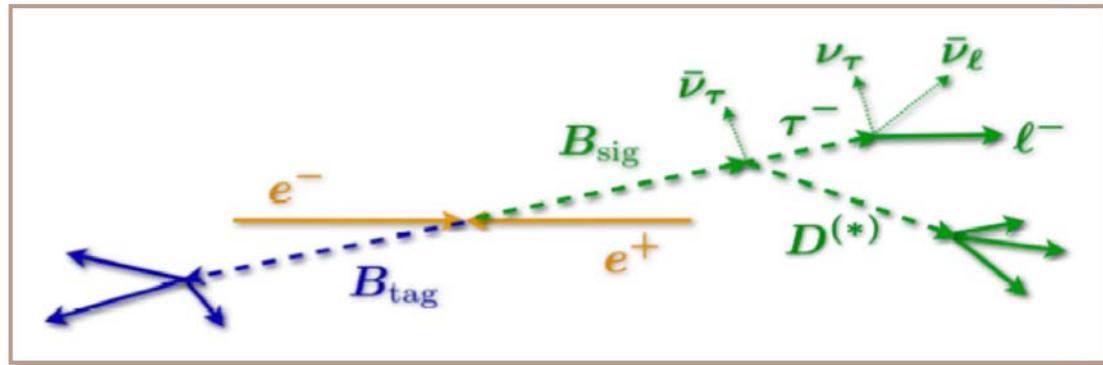
# Indirect $H^\pm$ searches at B factories

- $H^\pm$  predicted by many New Physics (NP) models, e.g. type-II 2-Higgs Doublet Model (2HDM)
  - DIRECT SEARCH @ hadron machines, e.g.:  $t \rightarrow b H^+$
  - INDIRECT SEARCH @ B factories, e.g.
    - quite accurate Standard Model (SM) predictions
      - $\sigma_{\text{SM}}(\mathcal{B})/\mathcal{B} \sim 5-7\%$  ( $B \rightarrow D^{(*)}\tau\nu$ ),  
 $25\%$  ( $B \rightarrow \tau\nu$ )
      - $H$  contribution at tree level
      - $H^\pm - \ell$  coupling  $\propto m_\ell$
    - experimentally challenging



# Analysis flow common features (I)

- 2 / 3 undetectable ν form  $B_{\text{sig}}$  and  $\tau$  decays: exploit kinematic constraints available at B-factories only (exclusive  $B\bar{B}$  production)

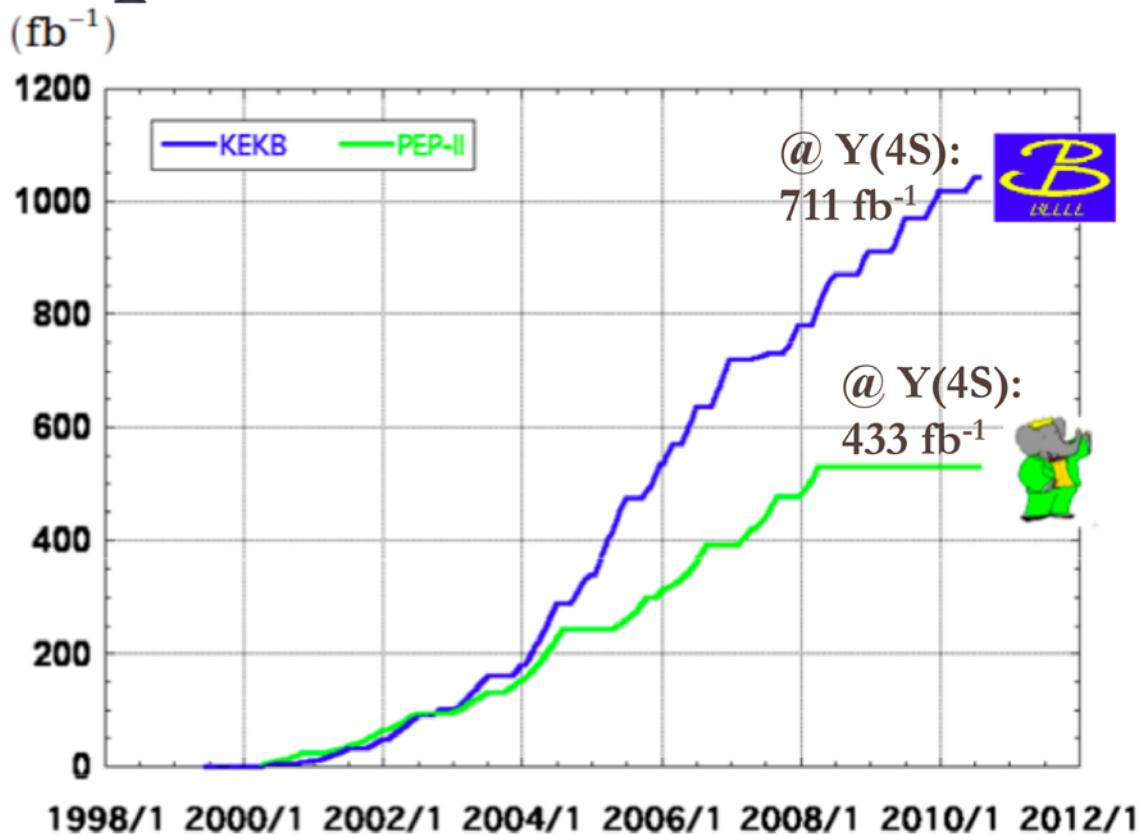


- Event reconstruction:
  - INCLUSIVE METHOD: reconstruct  $B_{\text{sig}}$ , then check compatibility of remaining particles with a B meson (=  $B_{\text{tag}}$ )  
→ higher efficiency and bkg contamination
  - EXCLUSIVE METHOD: completely reconstruct  $B_{\text{tag}}$  in hadronic (HAD) or semileptonic (SL) final states, then search for  $D^{(*)}\ell$  or  $\ell + \text{missing energy} (=B_{\text{sig}})$  in the rest of the event  
→ lower efficiency, higher purity

# Analysis flow common features (II)

- Background suppression: use of kinematics and global event variables, e.g.
  - $E_{ECL}/E_{\text{extra}} =$  neutral energy not associated with  $B_{\text{sig}}$  nor  $B_{\text{tag}}$
  - lepton momentum in  $B$  rest frame  $p_\ell^*$
  - missing mass  $m_{\text{miss}}^2$
- Extract signal and bkg yields by 1- or 2- dimentional Unbinned Maximum Likelihood (UML) fits
- Main systematic uncertainties due to
  - background parameterization in the fits
  - data/MC disagreement, affecting efficiency estimations

# Data samples



	$B \rightarrow \tau\nu$		$B \rightarrow D^{(*)}\tau\nu$
	HAD	SL	HAD
Belle	711	605	605
BaBar	426	418	426

- 85% of available statistics
- updated with FULL dataset



will focus on most recent HAD recoil analysis

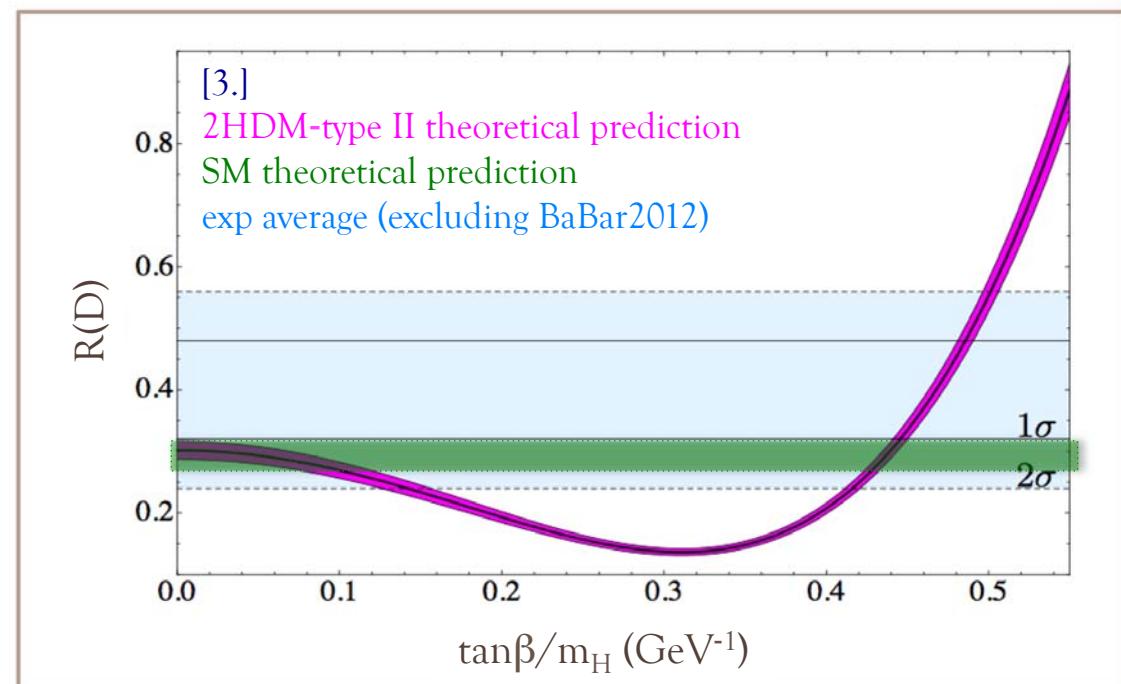
$B \rightarrow D^{(*)} \tau \nu$

# Ratios

$$R(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \rightarrow D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \rightarrow D^{(*)}\ell^-\bar{\nu}_\ell)}$$

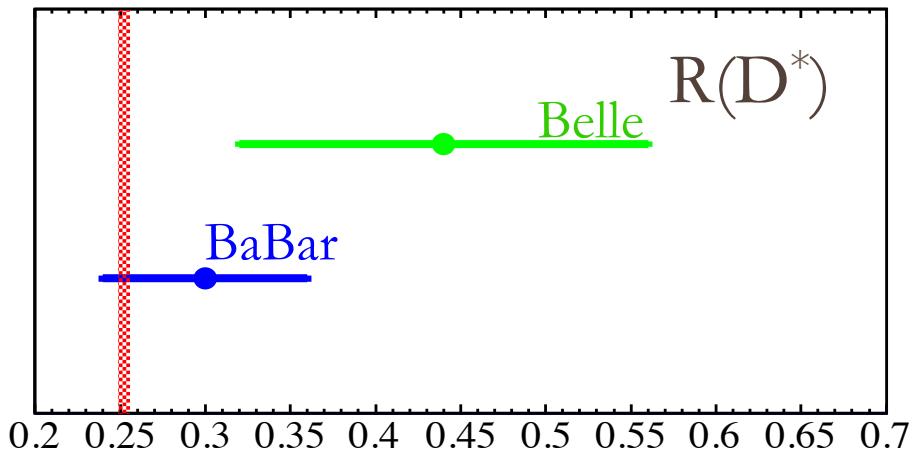
τ: signal sample  
 $\ell = e/\mu$  : normalization

- Several uncertainties from experiment (same final state for norm and sig) and theory ( $V_{cb}$ , form factors, ..) cancel
- SM predictions<sup>[1.,2.]</sup>:
  - $R(D) = 0.297 \pm 0.017$
  - $R(D^*) = 0.252 \pm 0.003$
- 2HDM-II vs SM:
  - $R(D)$  vs  $\tan\beta/m_H$



# Prior<sup>(\*)</sup> experimental status

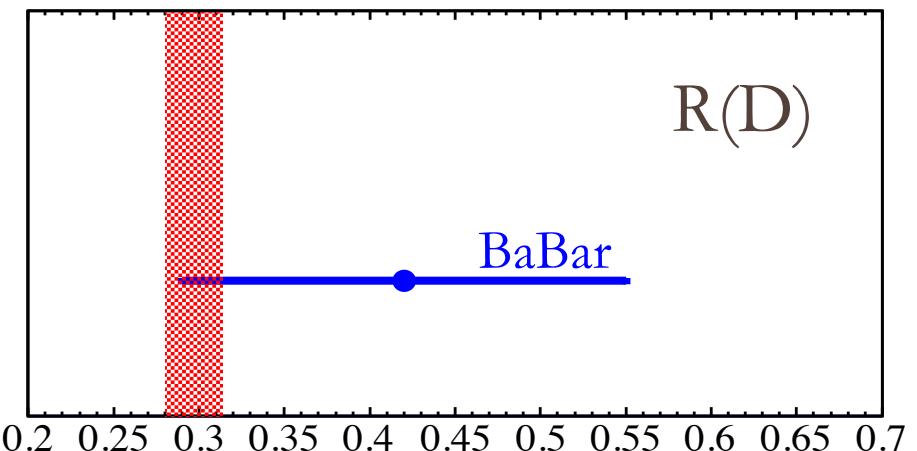
<sup>(\*)</sup>before the results discussed in this talk



Belle<sup>[4.]</sup> :  $R(D^*) = 0.44 \pm 0.12$

BaBar<sup>[5.]</sup> :  $R(D^*) = 0.30 \pm 0.06$

SM<sup>[1.,2.]</sup> :  $R(D^*) = 0.252 \pm 0.003$



BaBar<sup>[5.]</sup> :  $R(D) = 0.42 \pm 0.13$

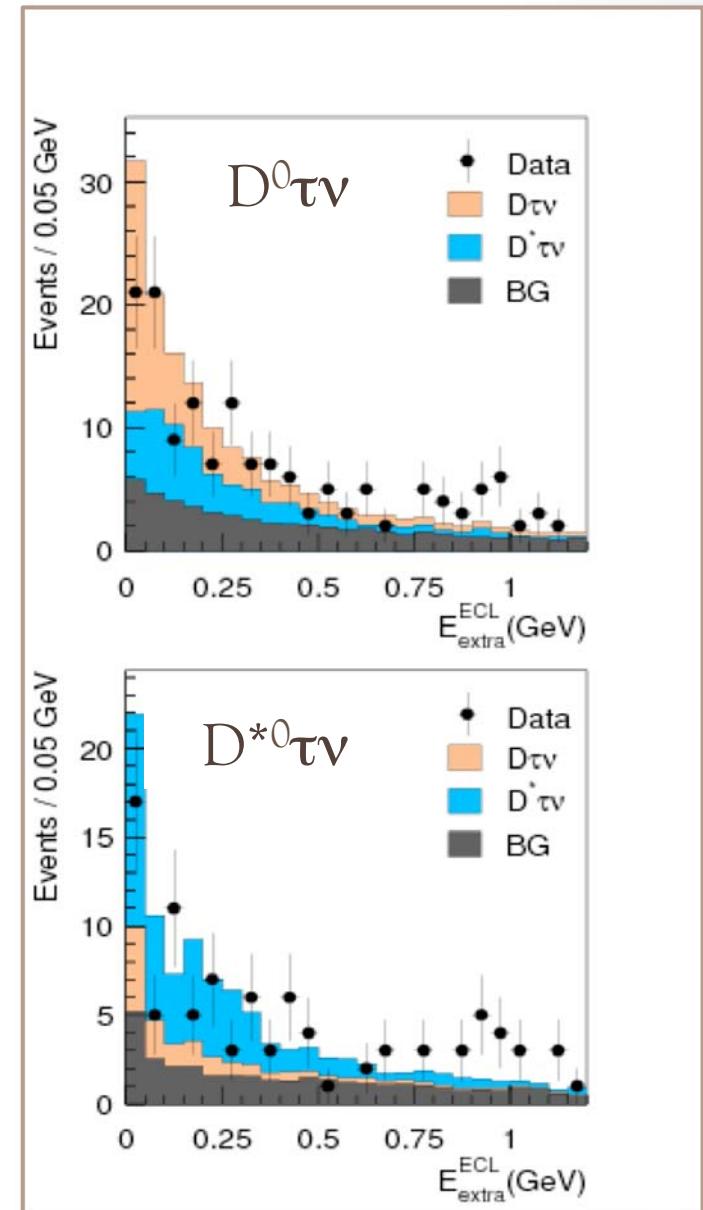
SM<sup>[1.,2.]</sup> :  $R(D) = 0.297 \pm 0.017$

# Belle 2009 HAD recoil analysis

- $\tau$  reconstructed in purely leptonic decay modes
- Signal yields from 2D-fits to  $m_{\text{miss}}^2$  and  $E_{\text{extra}}$
- Dominant systematic errors on  $R(D^{(*)})$ :
  - PDF parameterization (from MC simulation)
- Results:

	$N_{sig}$	$R$	$\Sigma(\Sigma_{stat})$
$D^- \tau^+ \nu$	$17.2^{+7.7}_{-6.9}$	$0.476^{+0.216+0.063}_{-0.193-0.054}$	$2.6(2.8)$
$\bar{D}^0 \tau^+ \nu$	$98.6^{+23.6}_{-25.0}$	$0.702^{+0.189+0.110}_{-0.180-0.091}$	$3.8(4.4)$
$D^{*-} \tau^+ \nu$	$25.0^{+7.2}_{-6.3}$	$0.481^{+0.140+0.058}_{-0.123-0.041}$	$4.7(5.9)$
$\bar{D}^{*0} \tau^+ \nu$	$99.8^{+22.2}_{-21.3}$	$0.468^{+0.140+0.062}_{-0.102-0.072}$	$3.9(5.2)$

- statistical errors dominates



# Belle 2010 inclusive analysis

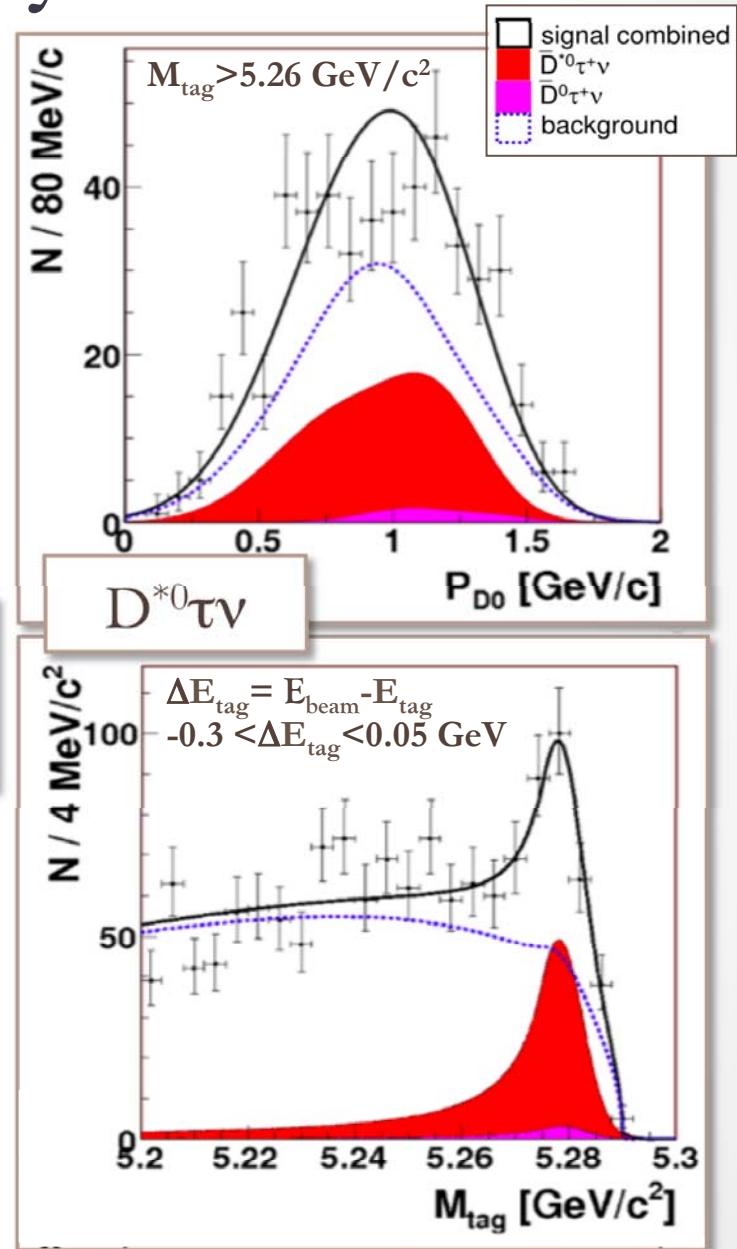
- Main differences wrt 2009 analysis
  - reconstruction: inclusive method,  $B^\pm$  only,  $\tau \rightarrow \pi\nu$  included, cleanest D final states only
  - yield extraction: 2D UML fit to  $M_{\text{tag}}$  and  $p_D$
- Results:

	$N_{\text{sig}}$	$\varepsilon(10^{-6})$	BF(%)	$\Sigma(n\sigma)$
$\bar{D}^{*0}\tau^+\nu$	$446^{+58}_{-56}$	$32.6 \pm 0.2$	$2.12^{+0.28}_{-0.27}$	8.8
$\bar{D}^0\tau^+\nu$	$146^{+42}_{-41}$	$30.0 \pm 0.4$	$0.77 \pm 0.22$	3.6

- $R(D^{(*)0})$  calculation:

$$R(D) = 0.35 \pm 0.11$$

$$R(D^*) = 0.43 \pm 0.08$$

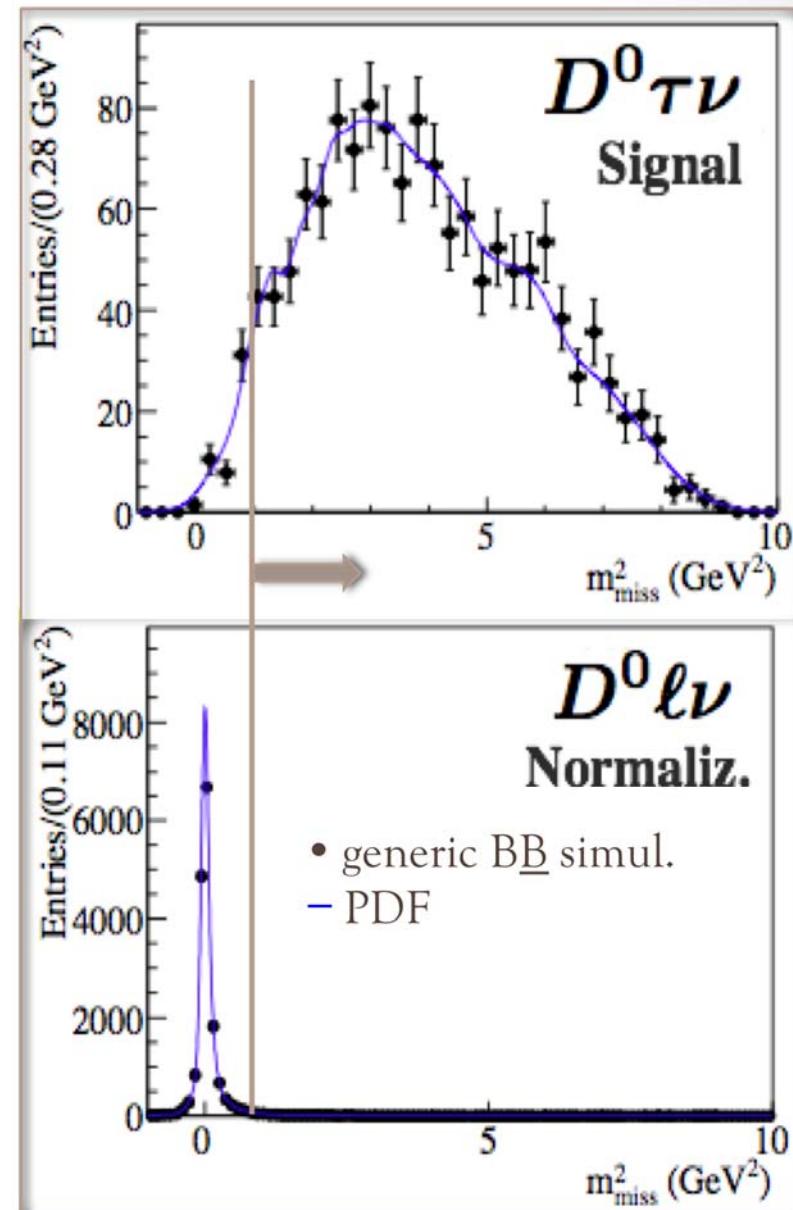




# BaBar: reconstruction and selection

- HAD  $B_{\text{tag}}$ ,  $\tau \rightarrow e/\mu\nu\nu$
- Improved particle-ID: lower  $p_\ell$  region wrt to previous analysis
- $q^2$  and  $|p_{\text{miss}}|$  cuts to reject  $D\ell\nu$  and neutrino-less ( $B\bar{B}$  combinatorial +  $q\bar{q}$ ) events, resp.
- Discriminant variables in a Boosted Decision Tree algorithm
- Signal-enriched  $m_{\text{miss}}^2$  region ( $> 1 \text{ GeV}^2/c^4$ )

sample	evt frac (%)
$D^{(*)}\tau\nu$	39
$D^{(*)}\ell\nu$	10
$q\bar{q}$	19
$D^{**}\ell/\tau\nu$	13
other $B\bar{B}$	19





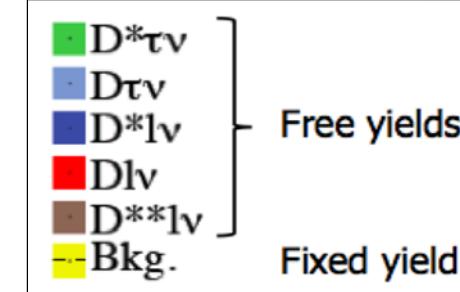
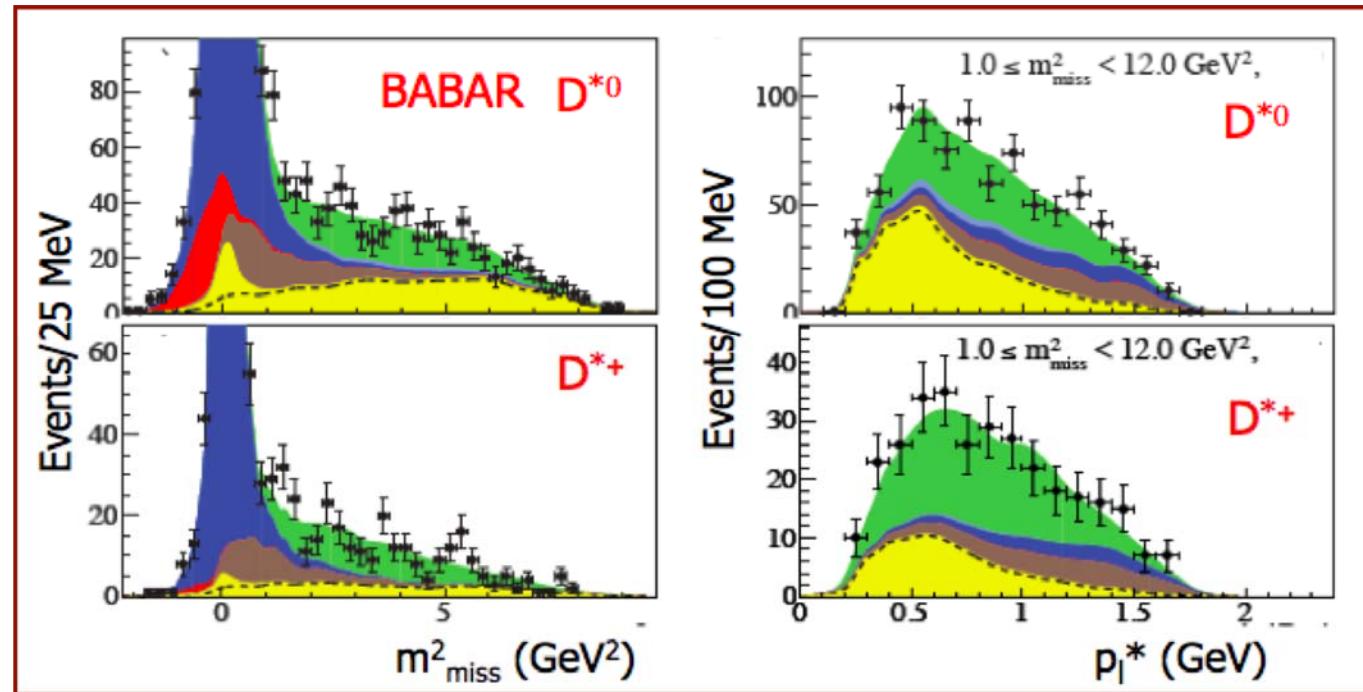
# BaBar: fit strategy

$$R(D^{(*)}) = \frac{\mathcal{B}(B \rightarrow D^{(*)} \tau \nu)}{\mathcal{B}(B \rightarrow D^{(*)} \ell \nu)} = \frac{N_{sig}}{N_{norm}} \cdot \frac{\varepsilon_{norm}}{\varepsilon_{sig}} \left[ \begin{array}{l} \text{from MC} \\ \text{simulation} \end{array} \right]$$

- Signal and normalization yields from 2D EML fit to  $m^2_{\text{miss}}$  and  $p_\ell^*$
- 8 simultaneously fitted samples: 4  $D^{(*)}\ell$  ( $\ell$  from normalization or signal channels) + 4  $D^{(*)}\pi^0\ell$
- Fitted yields :  $4 D^{(*)}\tau\nu + 4 D^{(*)}\ell\nu + 4 D^{**}\ell\nu$
- Fixed Yields (from MC simulation): Charge cross-feed +  $B\bar{B}$  combinatorial +  $e^+e^- \rightarrow q\bar{q}(\gamma)$
- Fit uses 56 fully 2D PDFs
  - approximated using non-parametric kernel estimators
  - shapes derived from MC simulation and fixed in the fit to data



# BaBar: Results

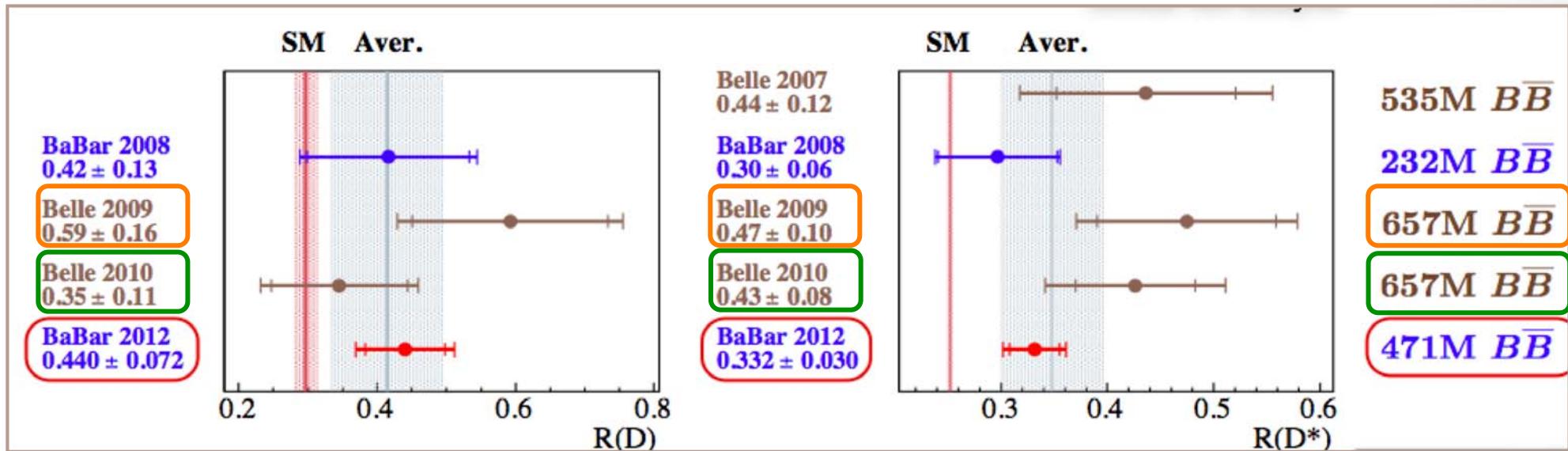


- Largest syst uncertainty on yield ratio due to  $D^{**}l\nu$  and other bkg knowledge
- Main syst error on efficiency ratio due to limited MC sample size

Decay	$R(D^{(*)})$	$\Sigma(\Sigma_{stat})$
$B^- \rightarrow D^{*0}\tau^-\bar{\nu}_\tau$	$0.322 \pm 0.032 \pm 0.022$	$9.4(11.3)$
$\bar{B}^0 \rightarrow D^{*+}\tau^-\bar{\nu}_\tau$	$0.355 \pm 0.039 \pm 0.021$	$10.4(11.6)$
$\bar{B} \rightarrow D^*\tau^-\bar{\nu}_\tau$	$0.332 \pm 0.024 \pm 0.018$	$13.2(16.4)$
$B^- \rightarrow D^0\tau^-\bar{\nu}_\tau$	$0.429 \pm 0.082 \pm 0.052$	$4.7(5.5)$
$\bar{B}^0 \rightarrow D^+\tau^-\bar{\nu}_\tau$	$0.469 \pm 0.084 \pm 0.053$	$5.2(6.1)$
$\bar{B} \rightarrow D\tau^-\bar{\nu}_\tau$	$0.440 \pm 0.058 \pm 0.042$	$6.8(8.4)$

First  $5\sigma$   
observation for  
 $B \rightarrow D\tau\nu$  !

# Comparison among measurements



- Averages do not include 2012 BaBar analysis
- Consistency among measurements
- New BaBar measurement improves the precision wrt older measurements
- Analysis on full Belle dataset and with improved HAD  $B_{tag}$  algorithm ongoing

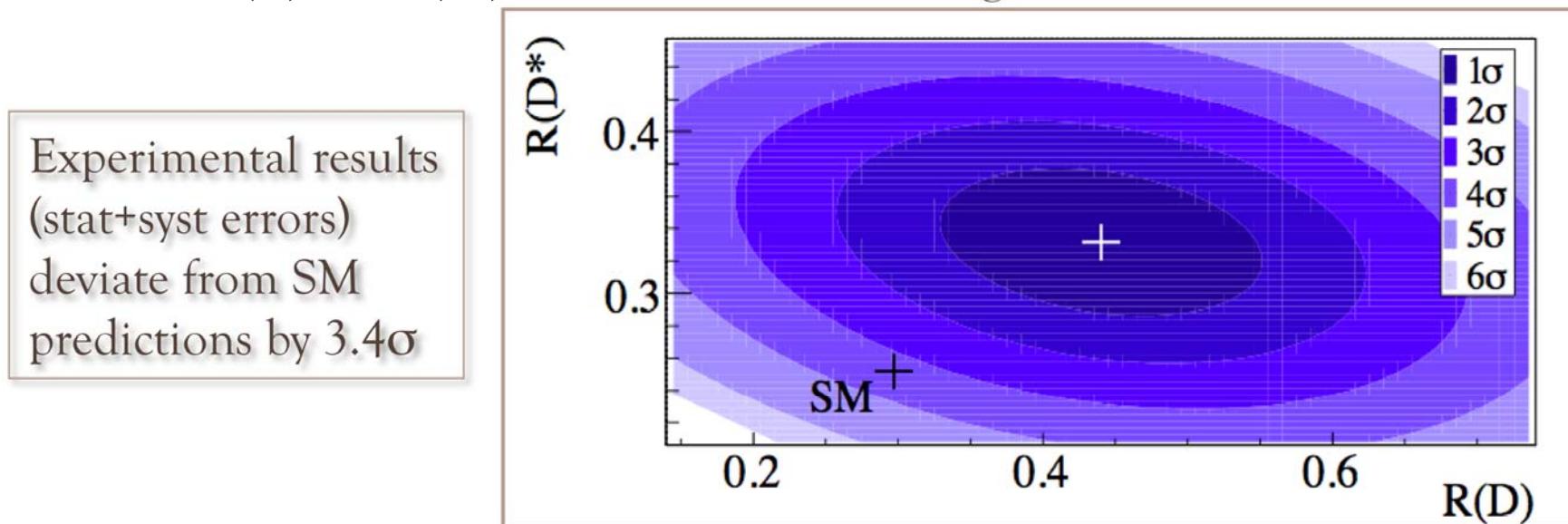


# BaBar: measurement vs SM

- BaBar measurements vs SM predictions:

	$R(D)$	$R(D^*)$
BABAR	$0.440 \pm 0.071$	$0.332 \pm 0.029$
SM	$0.297 \pm 0.017$	$0.252 \pm 0.003$
<b>Difference</b>	<b><math>2.0 \sigma</math></b>	<b><math>2.7 \sigma</math></b>

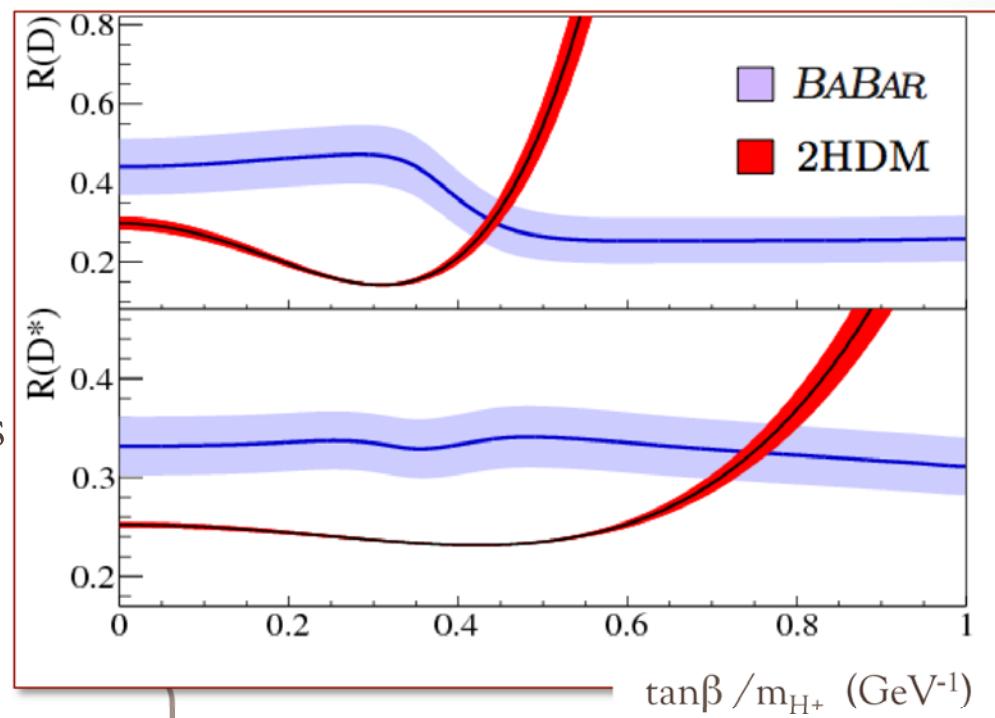
- Combine  $R(D)$  and  $R(D^*)$  measurements accounting for -0.27 correlation:





# BaBar: measurement vs type II 2HDM

- Re-weight BaBar simulation to account for changes in the hadronic currents due to 2HDM-II
  - re-compute  $\epsilon$  and PDFs and repeat the fit
  - large change of signal yield for  $\tan\beta/m_{H^+} > 0.4 \text{ GeV}^{-1}$
- Experimental data vs 2HDM-II:
  - $R(D)$ :  $\tan\beta/m_{H^+} = (0.44 \pm 0.02) \text{ GeV}^{-1}$
  - $R(D^*)$ :  $\tan\beta/m_{H^+} = (0.75 \pm 0.04) \text{ GeV}^{-1}$
- 2HDM-II excluded in the full  $\tan\beta$  vs  $m_{H^+}$  plane at 99.8% CL



computation for  $m_{H^+} > 10 \text{ GeV}$   
 lower mass region already excluded by  $B \rightarrow X_s \gamma$

$B \rightarrow \tau\nu$

# Theoretical motivations

- SM prediction:

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

- Inputs and numerical predictions:

- $f_B = (189 \pm 4)$  MeV [9.]
- excl.  $|V_{ub}|$  [10]

$$\mathcal{B}(B \rightarrow \tau \nu)_{SM} = (0.62 \pm 0.12) \times 10^{-4}$$

- incl.  $|V_{ub}|$  [11]

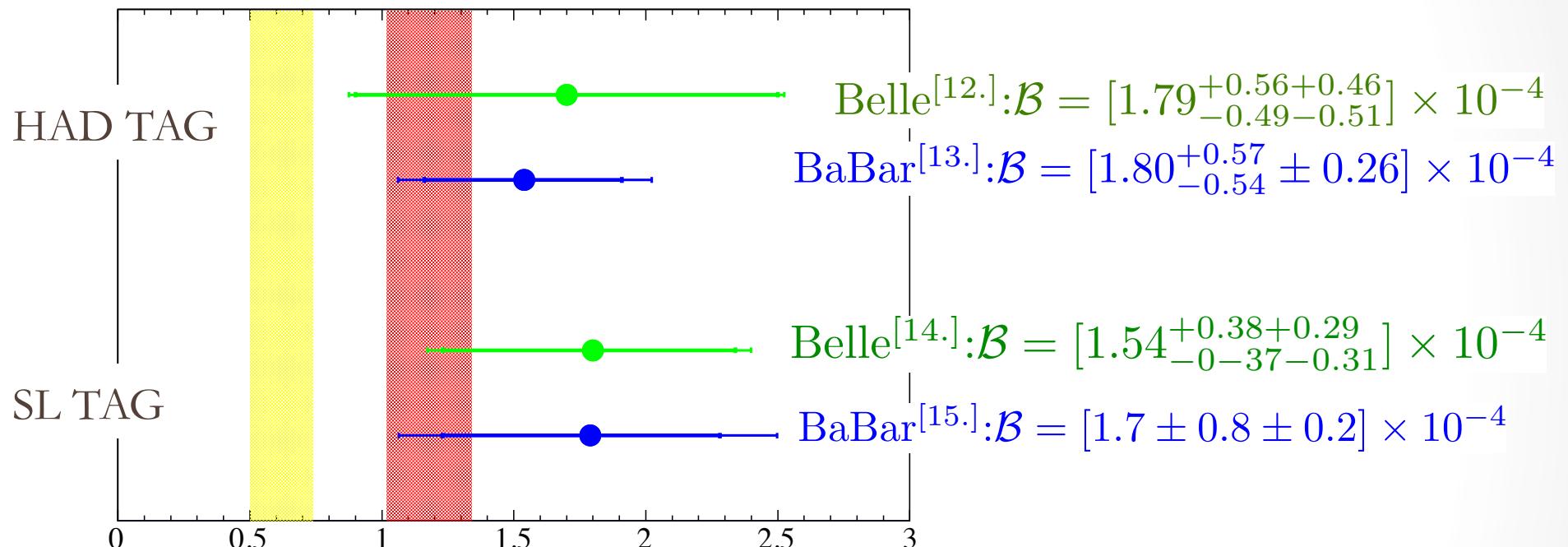
$$\mathcal{B}(B \rightarrow \tau \nu)_{SM} = (1.18 \pm 0.16) \times 10^{-4}$$

- 2HDM-II:

$$\mathcal{B}(B^- \rightarrow \tau^- \bar{\nu}_\tau)_{2HDM-II} = \mathcal{B}(B^- \rightarrow \tau^- \bar{\nu}_\tau)_{SM} \underbrace{\left(1 - \tan^2 \beta \frac{m_B^2}{m_H^2}\right)^2}_{r_H}$$

$r_H$

# Experimental status before 2012 updates



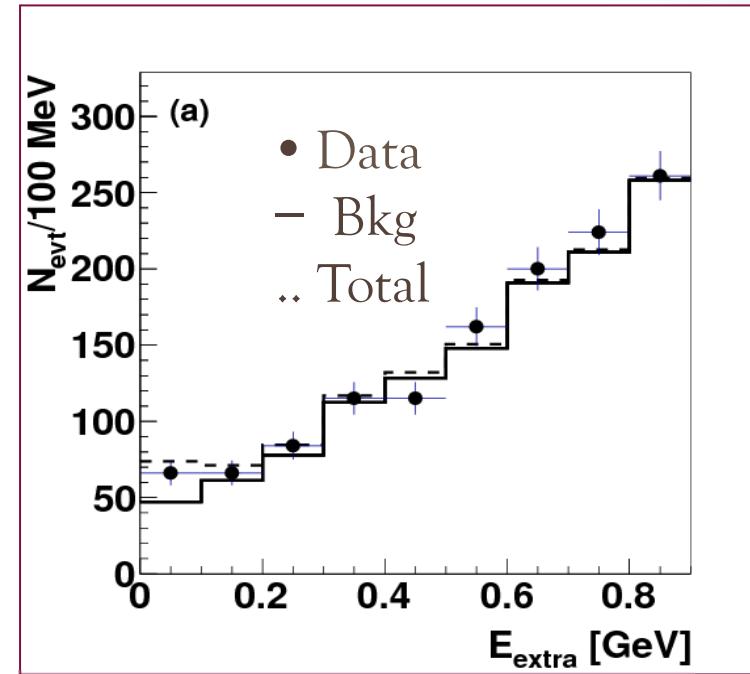
excl.  $|V_{ub}|$ :  $B(B \rightarrow \tau\nu)_{\text{SM}} = (0.62 \pm 0.12) \times 10^{-4}$

incl.  $|V_{ub}|$ :  $B(B \rightarrow \tau\nu)_{\text{SM}} = (1.18 \pm 0.16) \times 10^{-4}$



# BaBar analysis strategy

- HAD B<sub>tag</sub>,  $\tau \rightarrow e/\mu\nu\nu, \pi/\rho(\pi\pi^0)\nu$
- $\mathcal{B}$  extracted from EUML fit to E<sub>extra</sub>
  - Bkg shape fixed from m<sub>ES</sub> sideband and BB MC, signal shape from MC and control samples
  - E<sub>extra</sub> shape validated with “double-tag” sample (2 B’s reco’d in HAD modes or 1 HAD B and 1 SL B)
- Main syst: bkg PDF parameterization, data/MC disagreement in E<sub>extra</sub> shape, B<sub>tag</sub> efficiency correction



Decay Mode	$\mathcal{B} (\times 10^{-4})$	stat	syst
$\tau^+ \rightarrow e^+ \nu \bar{\nu}$	$0.35^{+0.84}_{-0.73}$		
$\tau^+ \rightarrow \mu^+ \nu \bar{\nu}$	$1.12^{+0.90}_{-0.78}$		
$\tau^+ \rightarrow \pi^+ \nu$	$3.69^{+1.42}_{-1.22}$		
$\tau^+ \rightarrow \rho^+ \nu$	$3.78^{+1.65}_{-1.45}$		
Combined	$1.83^{+0.53}_{-0.49} \pm 0.24$		

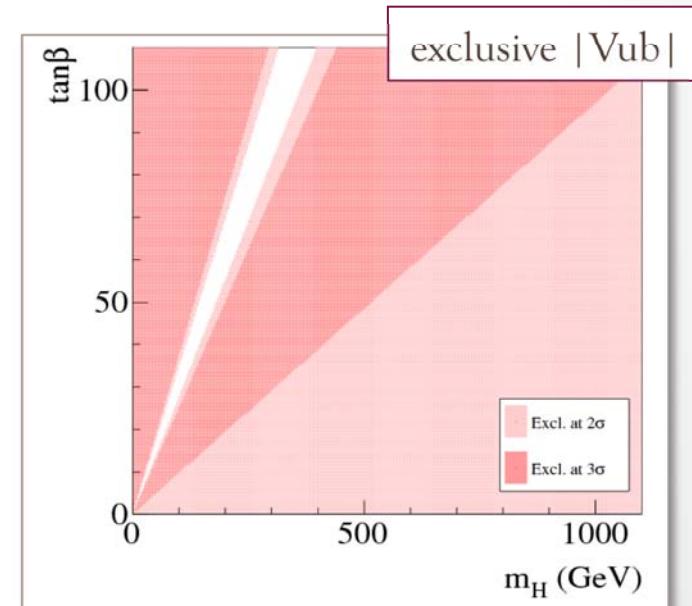
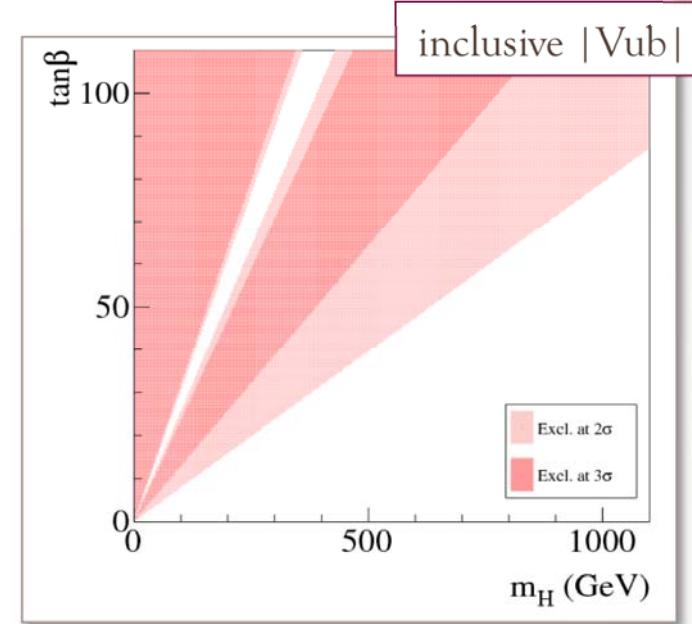
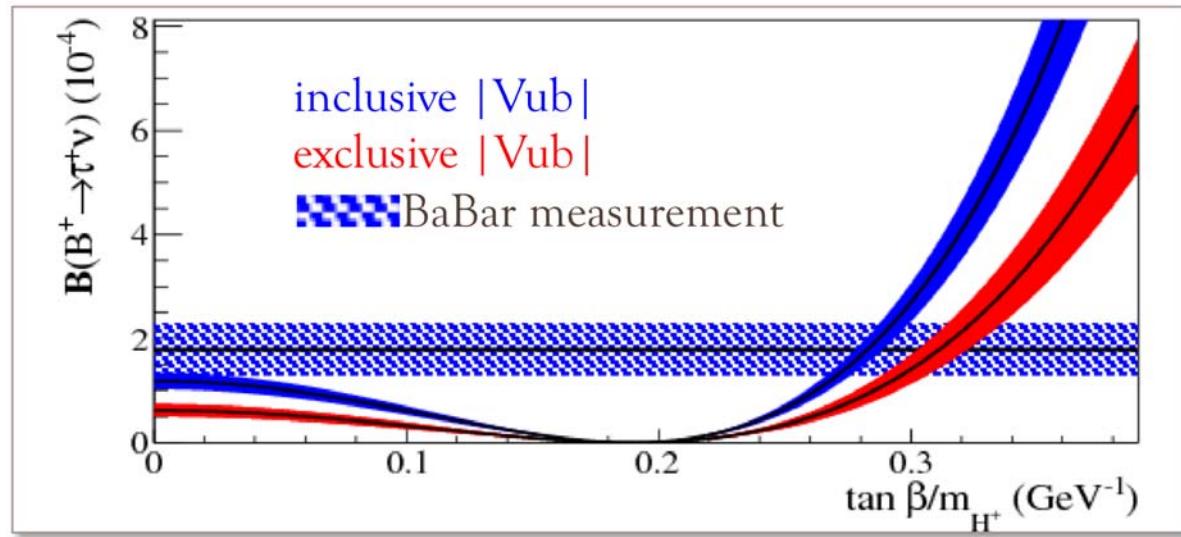
stat errors only



# BaBar result

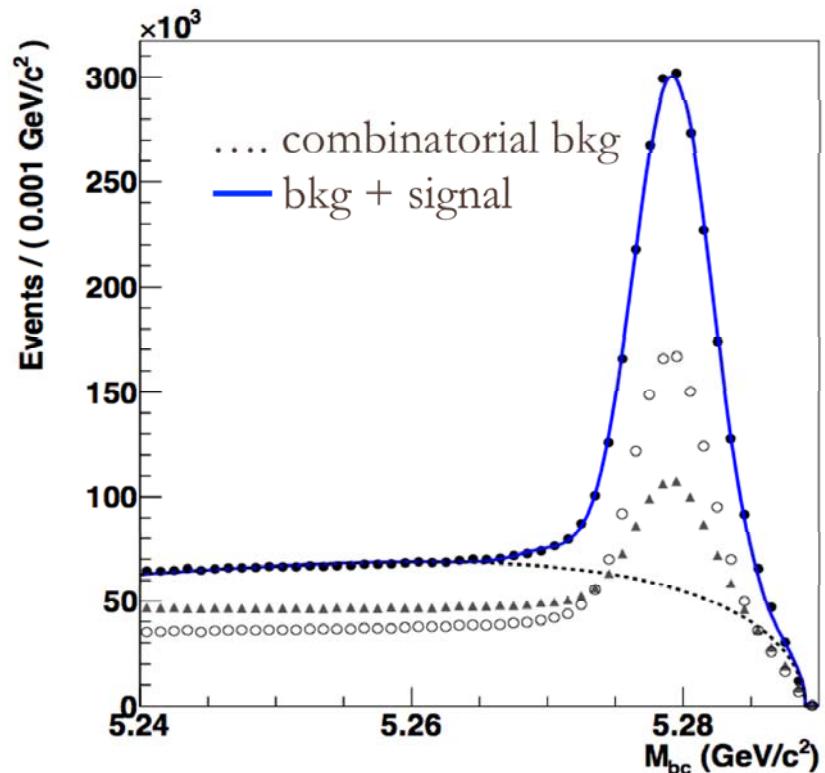
- Combine HAD and SL  $B_{tag}$  analysis<sup>[15.]</sup>:  

$$B(B \rightarrow \tau \nu) = (1.79 \pm 0.49) \times 10^{-4}$$
- 1.6  $\sigma$  (2.4  $\sigma$ ) excess wrt SM prediction with exclusive (inclusive)  $|V_{ub}|$
- Limits on 2HDM-II parameter space:



# Belle improved tagging method<sup>[17.]</sup>

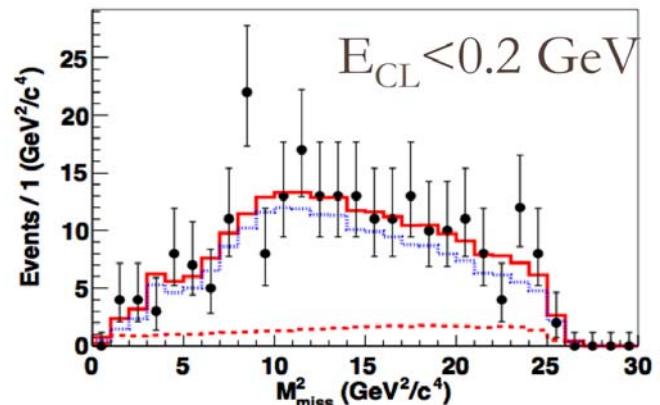
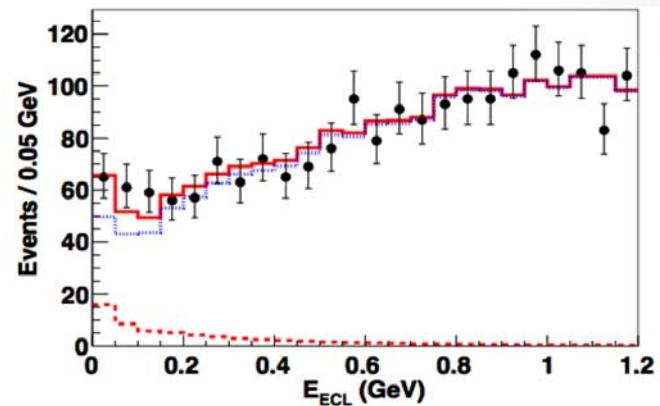
- Additional  $B_{tag}$  final states, 615 charged modes in total
- Discriminant variables in a NeuroBayes-based algorithm + selection in  $\Delta E$  and beam-constrained  $B$  mass ( $m_{BC}$ )
- Performances: efficiency: 0.24% (+1.7), purity: 65% (+1.2)



- new tag on reprocessed dataset
  - new tag on old dataset
  - ▲ old tag on old dataset  
(previous  $B \rightarrow \tau\nu$  analysis<sup>[13.]</sup>,  $414 \text{ fb}^{-1}$ )
- + 1.8 (larger dataset)  
+ 1.7 (tagging method)

# Belle analysis strategy

- HAD  $B_{\text{tag}}$ ,  $\tau \rightarrow e/\mu\nu\nu, \pi/\rho(\pi\pi^0)\nu$ 
  - signal
  - bkg
  - total
- VETO on extra  $K_L$  (new)
- yield extracted by 2D UML fit to  $E_{\text{ECL}} - m_{\text{miss}}^2$
- PDF = product of 1D histos (except  $\tau \rightarrow \pi\nu$  &  $\tau \rightarrow \rho(\pi\pi^0)\nu$  x-feed, 2D histo) from MC
- floating params: 4 signal yields + 1 bkg yield
  - fraction of different bkg from MC
  - dominant contamination from  $b \rightarrow c$



Sub-mode	$N_{\text{sig}}$	$\epsilon (10^{-4})$	$\mathcal{B} (10^{-4})$
$\tau^- \rightarrow e^- \bar{\nu}_e \nu_\tau$	$16^{+11}_{-9}$	3.0	$0.68^{+0.49}_{-0.41}$
$\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau$	$26^{+15}_{-14}$	3.1	$1.06^{+0.63}_{-0.58}$
$\tau^- \rightarrow \pi^- \nu_\tau$	$8^{+10}_{-8}$	1.8	$0.57^{+0.70}_{-0.59}$
$\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$	$14^{+19}_{-16}$	3.4	$0.52^{+0.72}_{-0.62}$
Combined	$62^{+23}_{-22}$	11.2	$0.72^{+0.27}_{-0.25}$

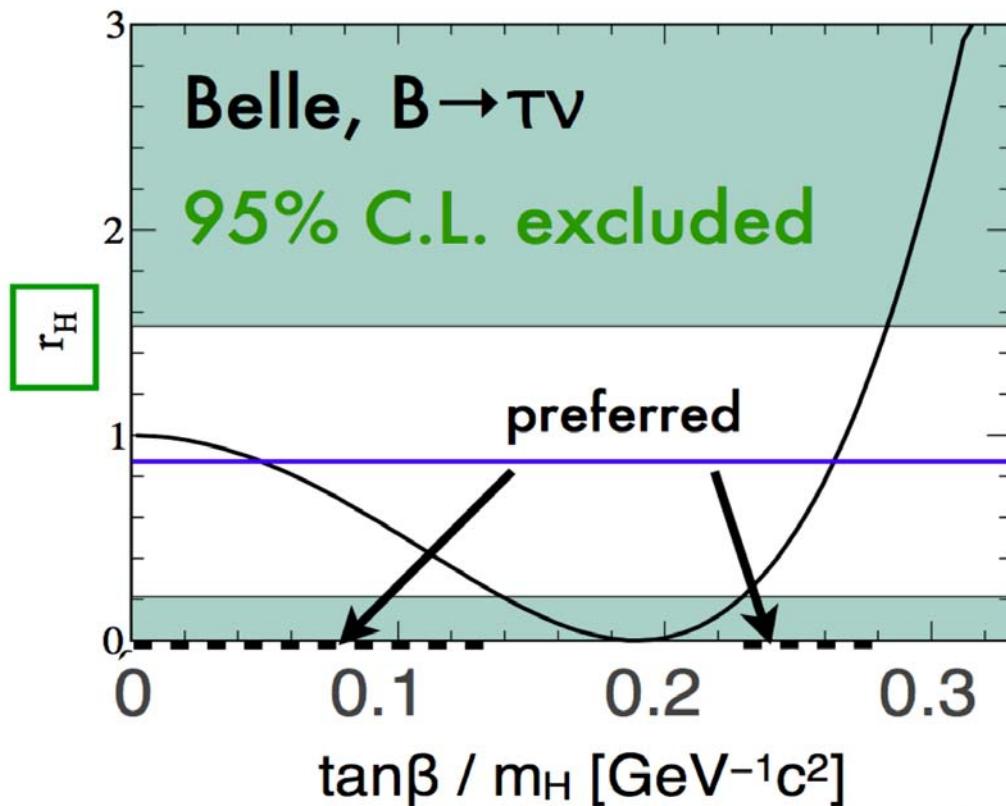
# Belle results

- Branching fractions:

$$\mathcal{B}(B \rightarrow \tau\nu) = (0.72^{+0.27}_{-0.25} \pm 0.11) \times 10^{-4} \quad 3\sigma \text{ sign. (Belle HAD)}$$

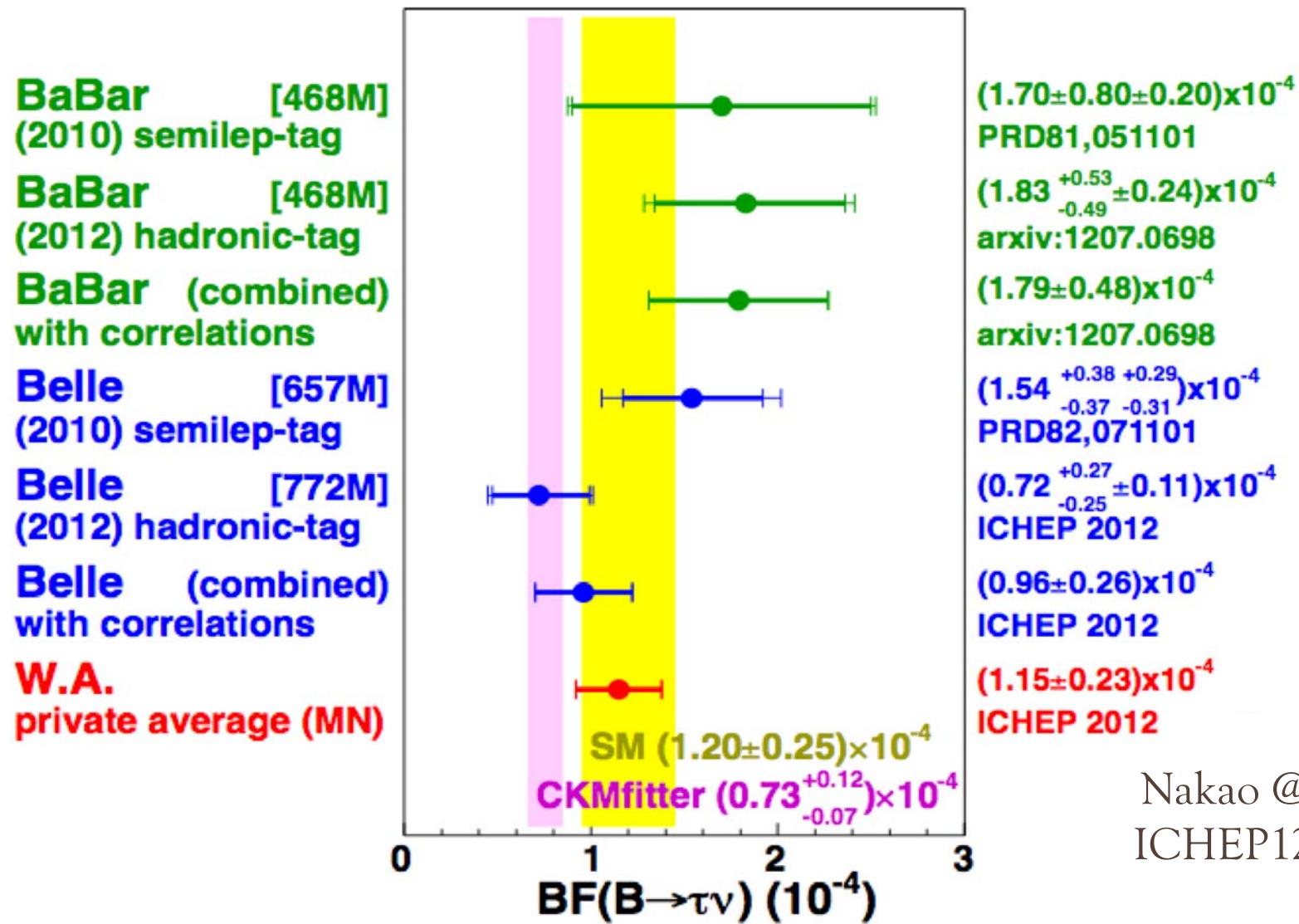
$$\mathcal{B}(B \rightarrow \tau\nu) = (0.96 \pm 0.26) \times 10^{-4} \quad 4\sigma \text{ sign. (Belle HAD + SL)}$$

- Constraints on type-II 2HDM:



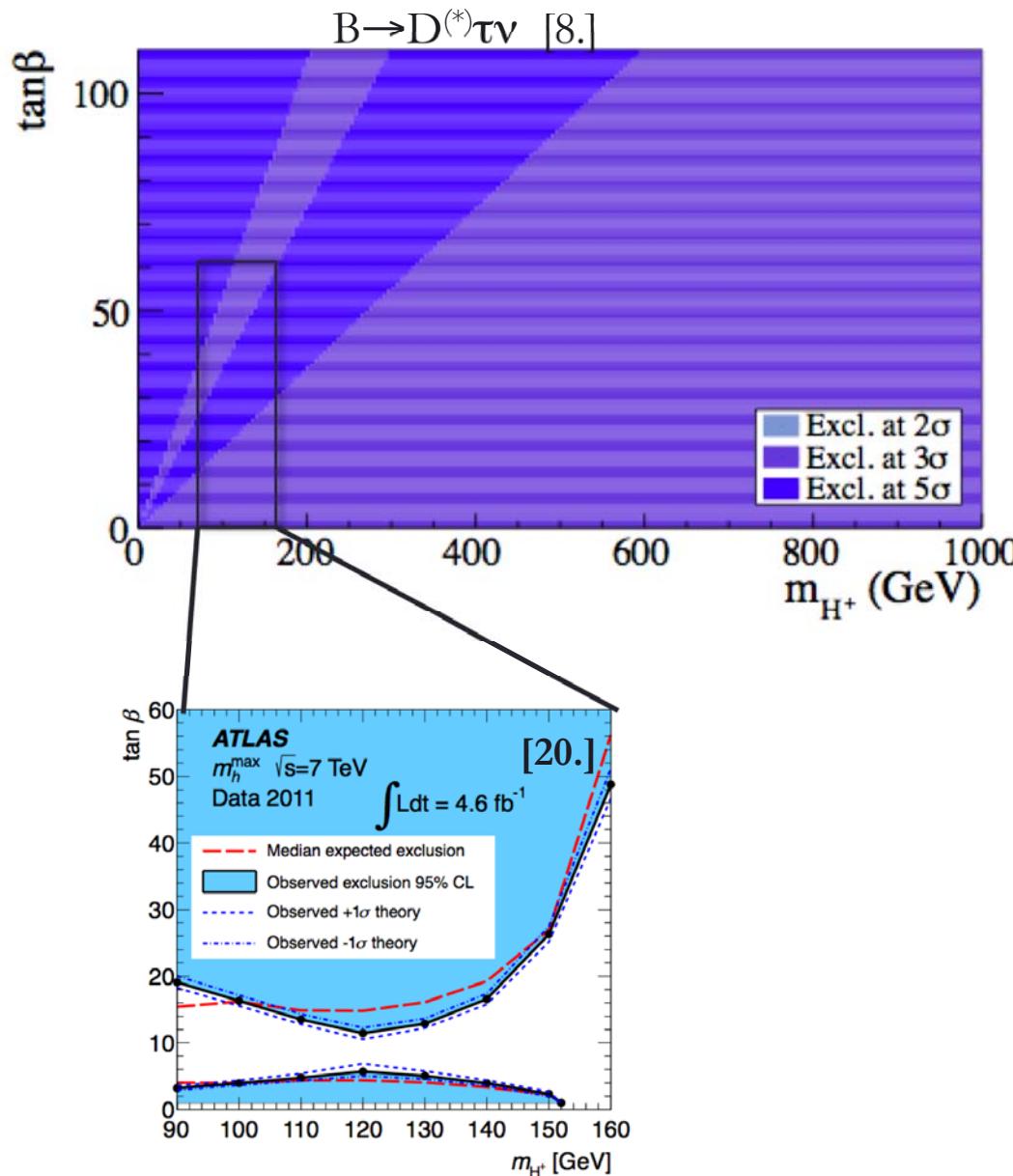
Y. Horii @ TAU12

# Comparison among measurements

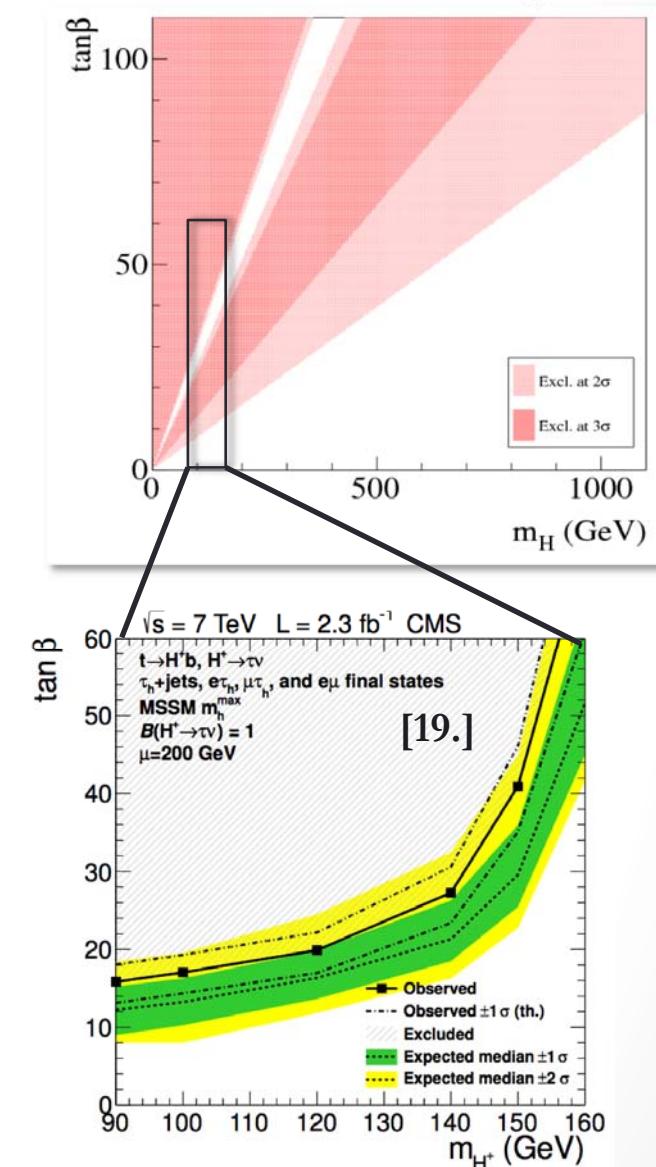


Nakao @  
ICHEP12

# Summary of constraints on type-II 2HDM



$B(B \rightarrow \tau\nu)$  (with inclusive  $V_{ub}$ ) [16.]



# Conclusions and perspectives

- Indirect  $H^\pm$  searches performed @ B factories in  $B \rightarrow D^{(*)}\tau\nu$  and  $B \rightarrow \tau\nu$  channels
- $B \rightarrow \tau\nu$  results consistent with SM within errors
- $B \rightarrow D^{(*)}\tau\nu$  BaBar results deviate from SM expectations at  $3.4\sigma$  level
- 2HDM excluded @ 99.8 C.L. % (most stringent constraints from BaBar  $B \rightarrow D^{(*)}\tau\nu$ )
- BaBar measurement updated on full statistics
  - improvement on  $B \rightarrow D^{(*)}\tau\nu$  by considering additional reconstructed final states under investigation
- $B \rightarrow D^{(*)}\tau\nu$  Belle measurement to be updated on full statistics (15% more)
- Much more statistics with Belle II experiment.

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