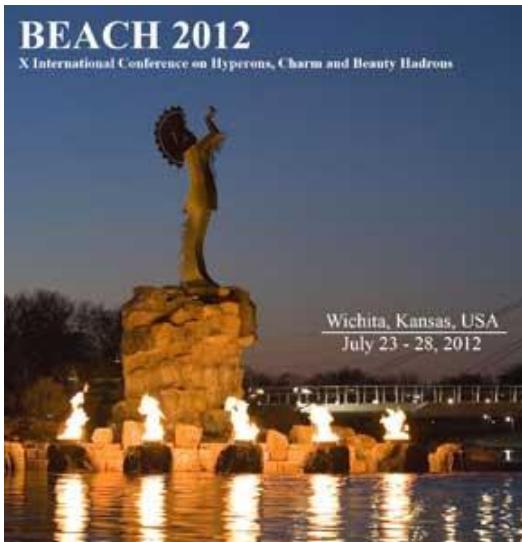


# Studies of $B \rightarrow \tau v$ and $B \rightarrow D^{(*)} \tau v$ at BABAR

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On behalf of the BABAR collaboration



BEACH 2012  
Wichita, Kansas  
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# Introduction

- Goal: test Standard Model (SM) predictions and search for new physics effects (charged Higgs).
- $B \rightarrow \tau \nu$  leptonic decays.
  - [arXiv:1207.0698](#)
  - Submitted to Phys. Rev. D.
- $B \rightarrow D^{(*)} \tau \nu$  semileptonic decays.
  - [arXiv:1205.5442](#)
  - Submitted to Phys. Rev. Lett.

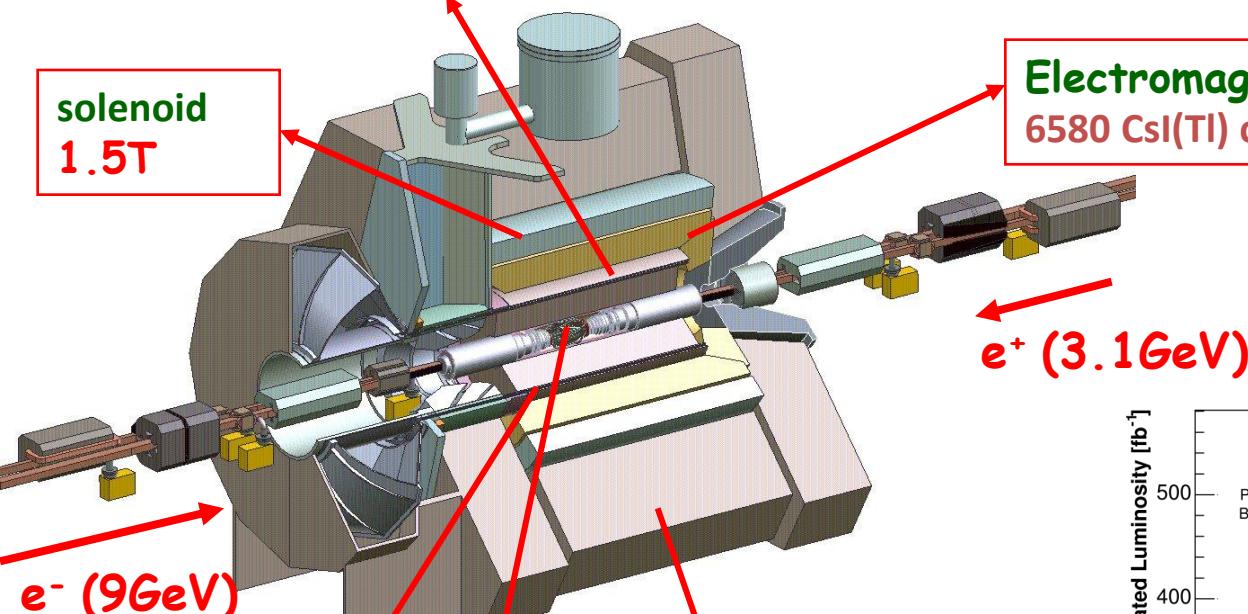
# Detector and data sample

Cherenkov detector (DIRC)

144 quartz bars and 11000 PMTs

solenoid  
1.5T

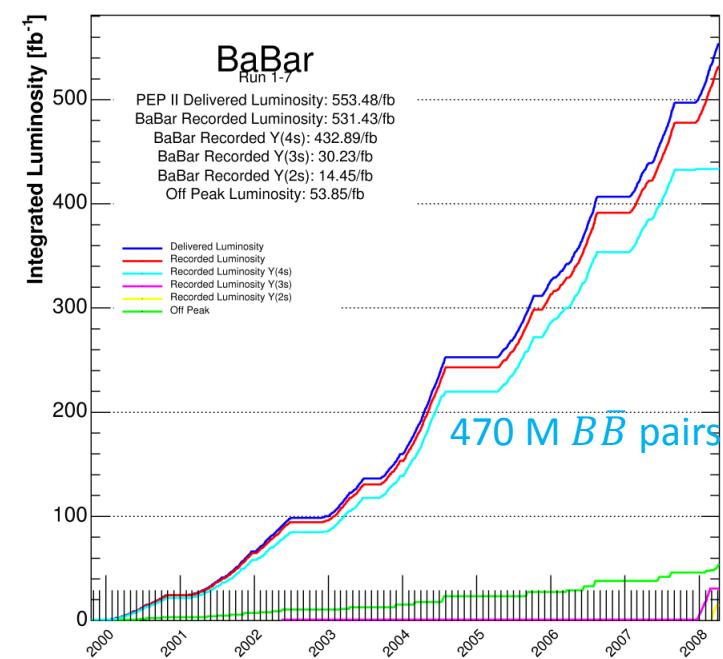
Electromagnetic calorimeter  
6580 CsI(Tl) crystals



Drift chamber  
40 layers

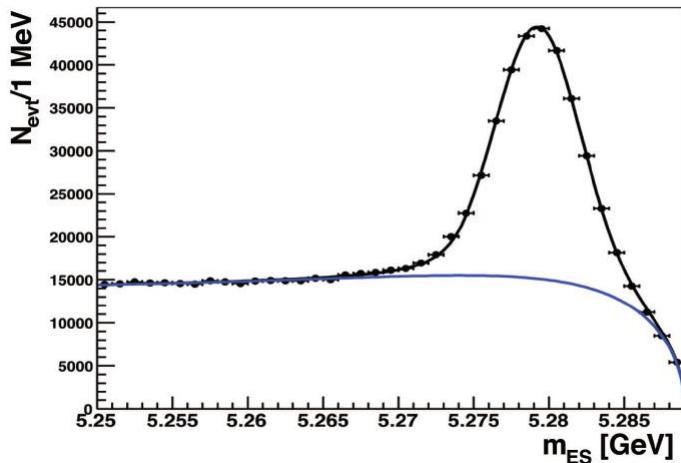
Si vertex tracker  
5 layers

$\mu$  chambers  
RPC / LST



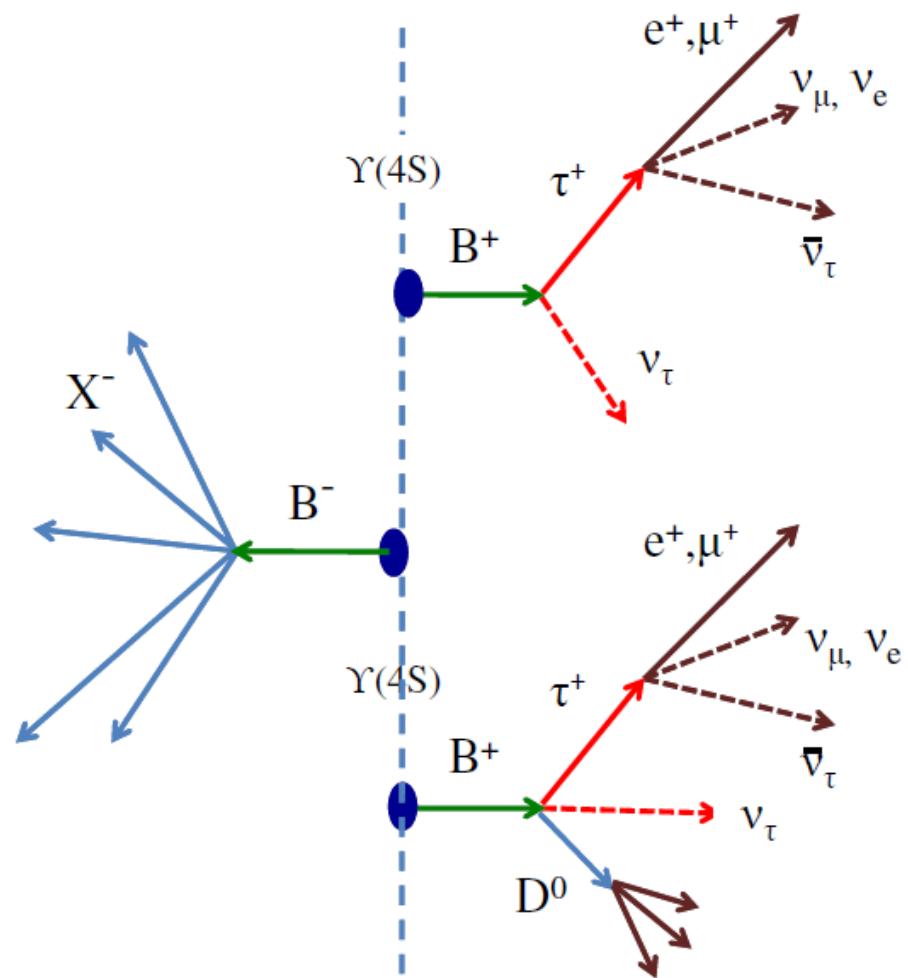
# Common tagging method

- Neutrinos in the final state: lack of kinematical constraints.
- Look for signal in rest of the event after **full reconstruction of one B** in hadronic decays.



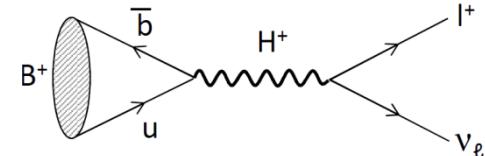
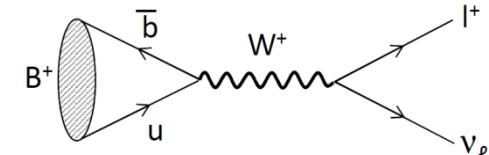
Tag this B

Then look for signal



# B → τ ν : motivation

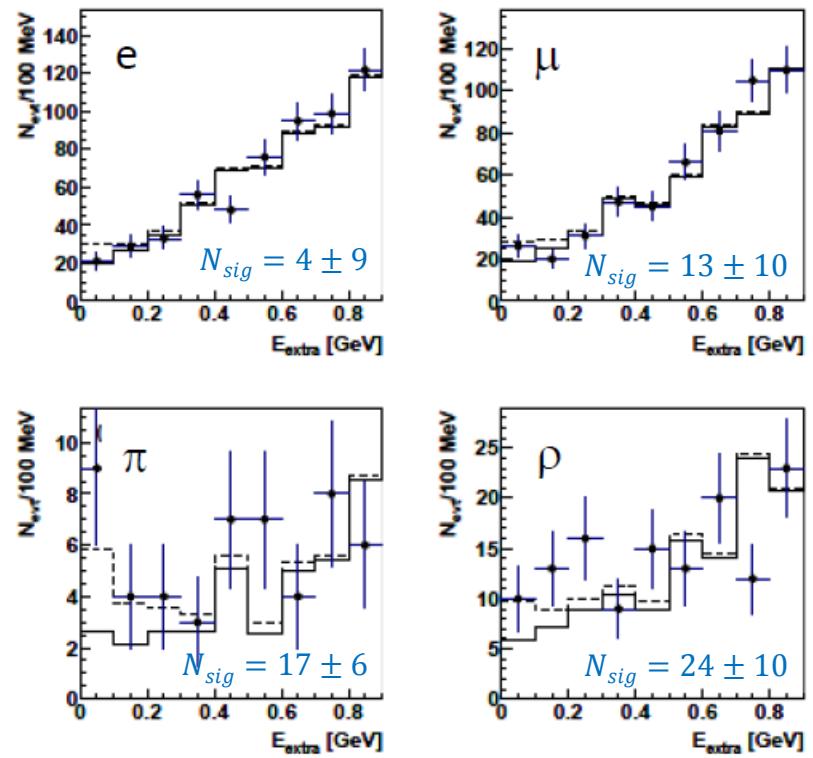
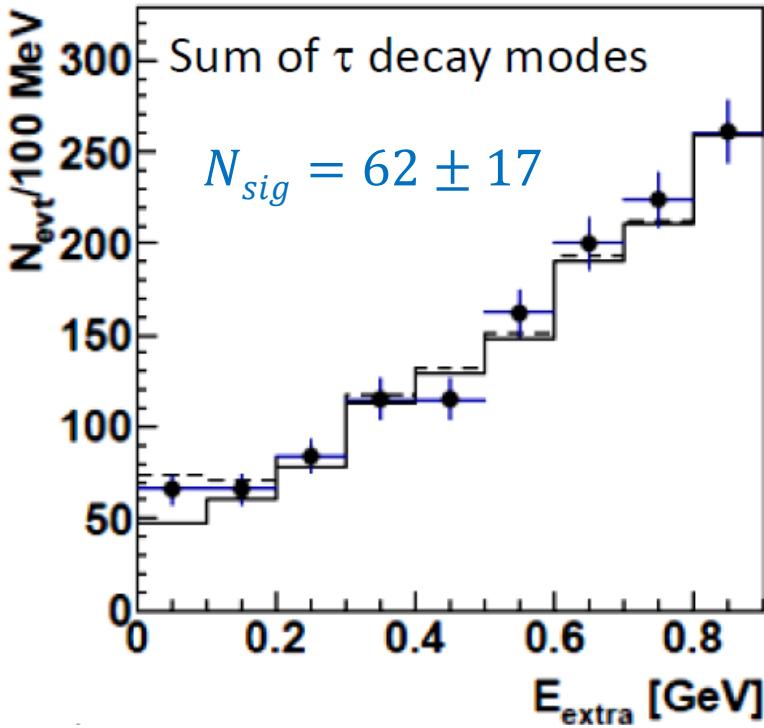
- $B(B \rightarrow l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$
- Leptonic B decays to test SM predictions.
  - Very clean theoretically.
  - Uncertainties from  $f_B$  and  $|V_{ub}|$ .
  - $B \rightarrow \mu\nu$  and  $B \rightarrow e\nu$  out of reach at current B factories.
- Probe of physics beyond the SM.
  - Decay can be mediated by a charged Higgs.
- $B(B \rightarrow l\nu)_{2HDM} = B(B \rightarrow l\nu)_{SM} \left(1 - \tan^2 \beta \frac{m_B^2}{m_H^2}\right)^2$



# $B \rightarrow \tau v$ : analysis strategy

- Maximum likelihood fit to the residual energy ( $E_{\text{extra}}$ ) in the calorimeter.
- Simultaneous fit in 4 modes:
  - $\tau \rightarrow e\nu\bar{\nu}$ ,  $\tau \rightarrow \mu\nu\bar{\nu}$ ,  $\tau \rightarrow \pi\nu$ ,  $\tau \rightarrow \rho\nu$ .
  - Require one single charged particle.
- $E_{\text{extra}}$  shape estimated from:
  - Data sideband (combinatorial background)
  - MC (signal and peaking background)
    - Validated using double tagged events.

# B → τ ν : fit result



- $B(B \rightarrow \tau \nu) = (1.83^{+0.53}_{-0.49}(stat.) \pm 0.24(syst.)) \cdot 10^{-4}$
- Main systematics uncertainty from background PDF.
- $3.8\sigma$  excess of events over background.

# B → τ ν : result discussion

- New BABAR result:

$$\bullet \quad B(B \rightarrow \tau \nu) = (1.83^{+0.53}_{-0.49} \pm 0.24) \cdot 10^{-4}$$

468 M B $\bar{B}$

- Comparison with other measurements:

Experiment	Tag	Branching Fraction ( $\times 10^{-4}$ )	
BABAR	hadronic [8]	$1.8^{+0.9}_{-0.8} \pm 0.4 \pm 0.2$	383 M B $\bar{B}$
BABAR	semileptonic [9]	$1.7 \pm 0.8 \pm 0.2$	459 M B $\bar{B}$
Belle	hadronic [10]	$1.79^{+0.56+0.46}_{-0.49-0.51}$	449 M B $\bar{B}$
Belle	semileptonic [11]	$1.54^{+0.38+0.29}_{-0.37-0.31}$	657 M B $\bar{B}$

$$- \quad \text{BELLE (ICHEP 2012): } B(B \rightarrow \tau \nu) = (0.72^{+0.27}_{-0.25} \pm 0.11) \cdot 10^{-4}$$

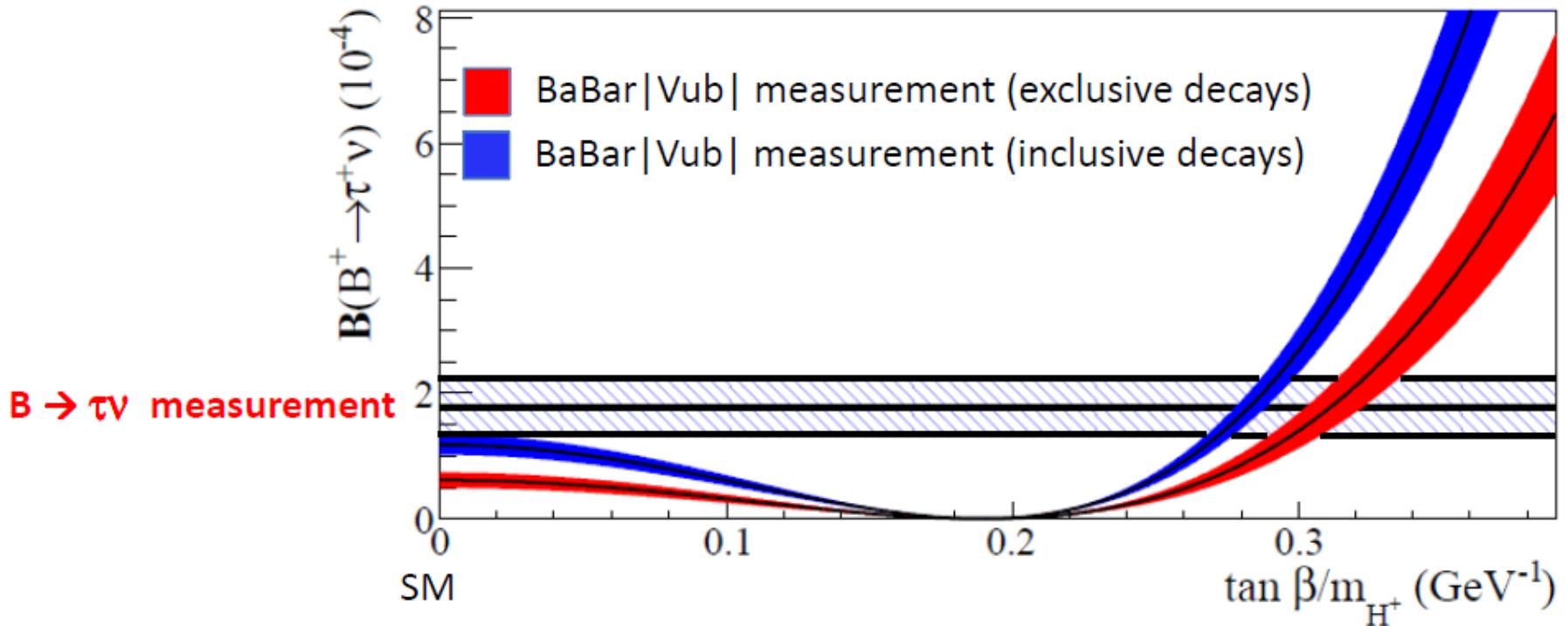
722 M B $\bar{B}$

- Comparison with SM prediction (using  $f_B = (189 \pm 4)$  MeV): HPQCD arXiv:1202.4914
  - 2.4 σ with  $B_{SM}(B \rightarrow \tau \nu) = (0.62 \pm 0.12) \cdot 10^{-4}$  ( $|V_{ub}|$  exclusive PoS(EPS-HEP2011)155).
  - 1.6 σ with  $B_{SM}(B \rightarrow \tau \nu) = (1.18 \pm 0.16) \cdot 10^{-4}$  ( $|V_{ub}|$  inclusive arXiv:1112.0702).

# $B \rightarrow \tau \nu$ : 2HDM model

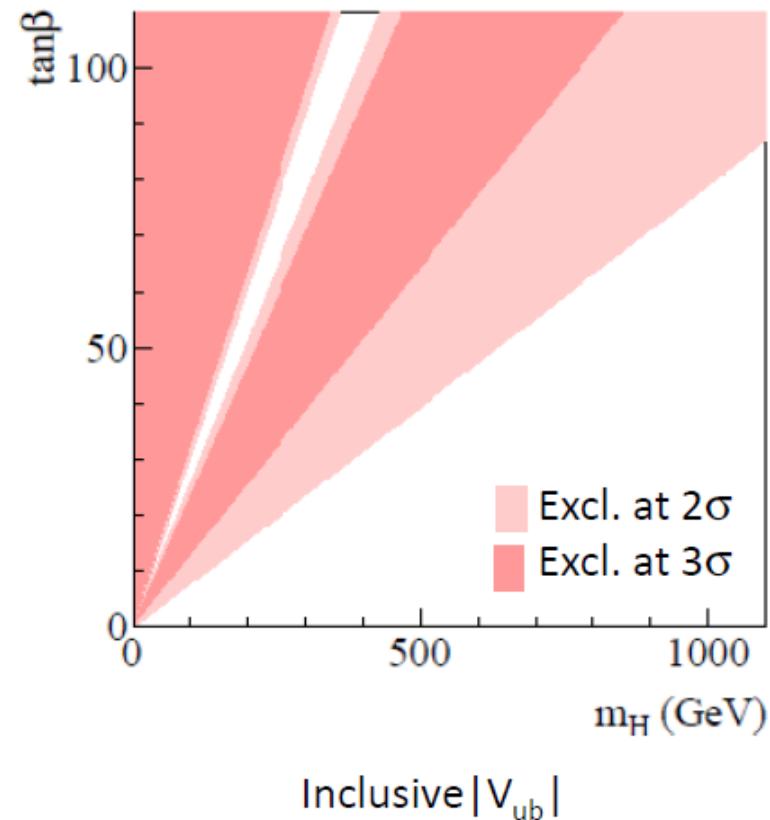
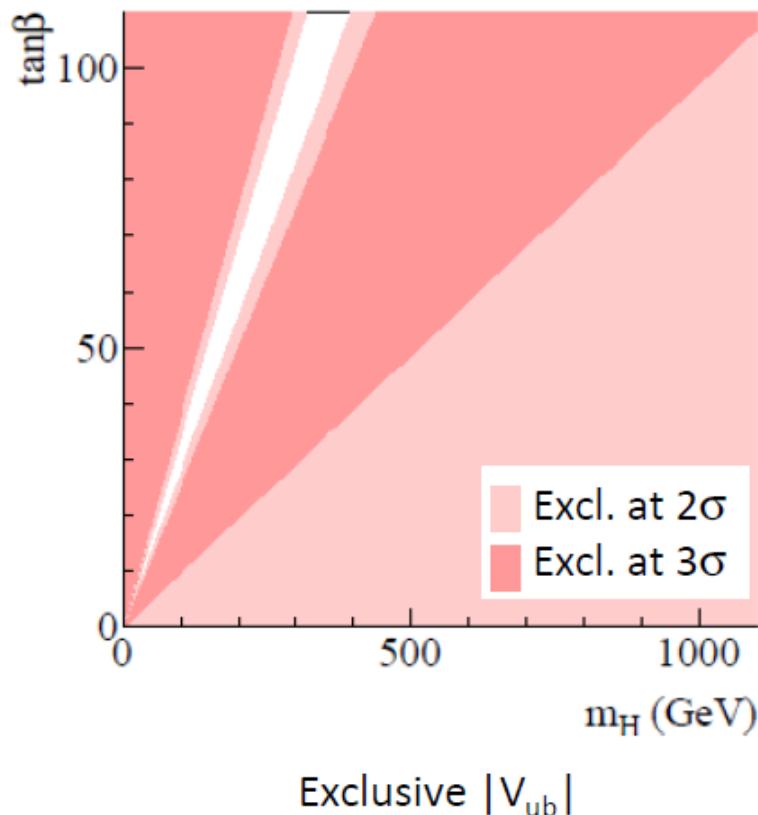
- In the 2 Higgs Doublet Model of type II:

$$B(B \rightarrow l\nu)_{2HDM} = B(B \rightarrow l\nu)_{SM} \left(1 - \tan^2\beta \frac{m_B^2}{m_{\tau\tau}^2}\right)^2$$



# $B \rightarrow \tau \nu$ : constraints in 2HDM (II)

- Most of the parameter space excluded at 95% CL with exclusive  $|V_{ub}|$ .
- 95% CL exclusion up to 1 TeV at very high  $\tan\beta > 70$  with inclusive  $|V_{ub}|$ .

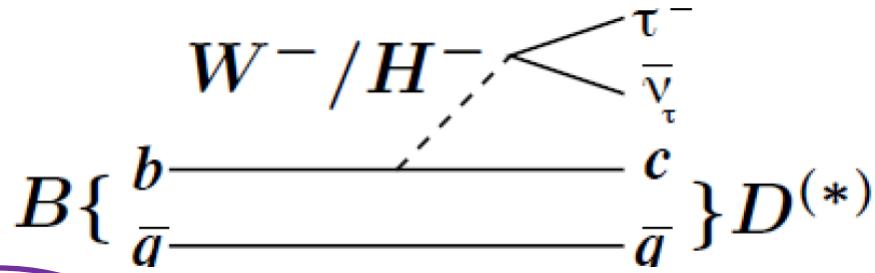


# B → D(\*) τ ν : motivation

- Semileptonic decays with a τ.

$$\frac{d\Gamma_\tau}{dq^2} = \frac{G_F^2 |V_{cb}|^2 |p_{D^{(*)}}| q^2}{96\pi^3 m_B^2} \left(1 - \frac{m_\ell^2}{q^2}\right)^2 \left[ (|H_+|^2 + |H_-|^2 + |H_0|^2) \left(1 + \frac{m_\ell^2}{2q^2}\right) + \frac{3m_\ell^2}{2q^2} |H_s|^2 \right]$$

only for B → D\* τ ν



H⁻ enters here

- Test the SM by measuring the ratios:

$$R(D) = \frac{B(\bar{B} \rightarrow D \tau \bar{\nu})}{B(\bar{B} \rightarrow D l \bar{\nu})} \text{ and } R(D^*) = \frac{B(\bar{B} \rightarrow D^* \tau \bar{\nu})}{B(\bar{B} \rightarrow D^* l \bar{\nu})}.$$

- Several theoretical and experimental uncertainties cancel in the ratio.

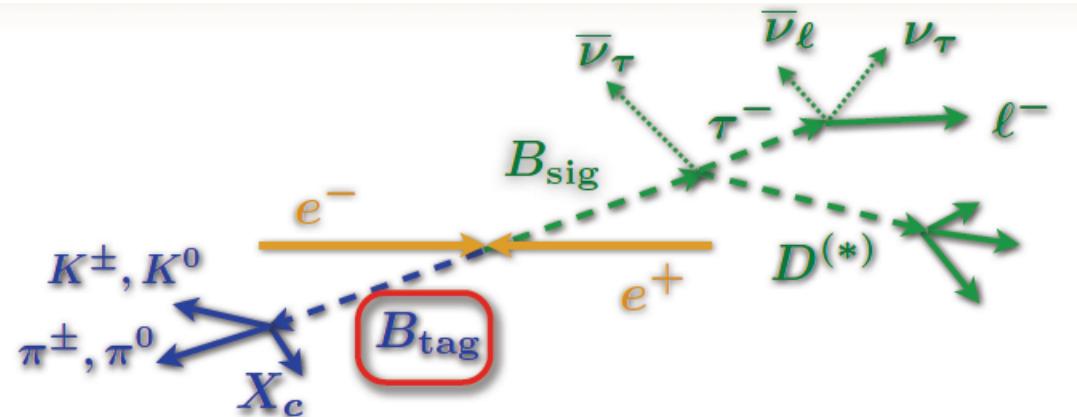
- Sensitive to additional amplitudes.

- Charged Higgs (entering through the scalar amplitude).

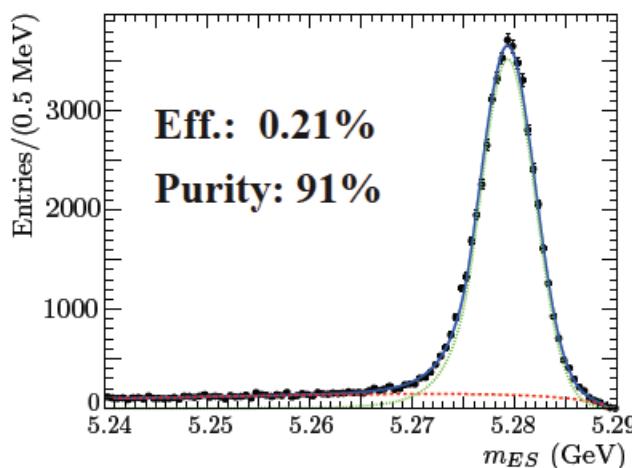
# $B \rightarrow D^{(*)} \tau \nu$ : tagging B

- Fully reconstructed tag B

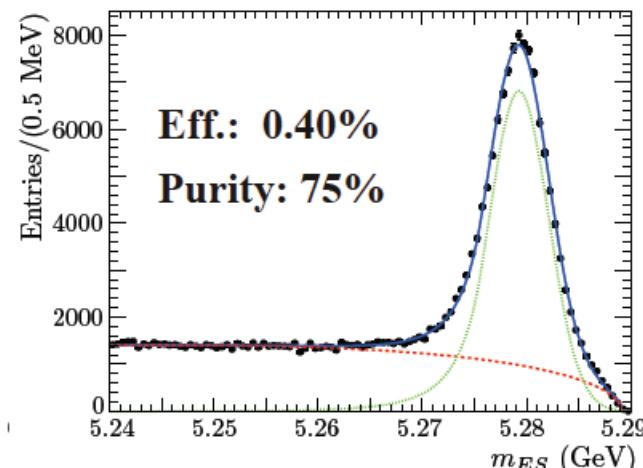
- Efficiency 2x previous analysis



Old  $B_{\text{tag}}$ :  $X_c = D, D^*$   
630 decay chains



New  $B_{\text{tag}}$ :  $X_c = D, D^*, D_s^+, D_s^{*+}, J/\Psi$   
1,768 decay chains



# $B \rightarrow D^{(*)} \tau \nu$ : analysis strategy

- Reconstruct  $\tau$  in purely leptonic decay.
  - Same reconstructed particles in signal and normalization modes.
  - Only number of neutrinos is different.
- Unbinned maximum likelihood fit.
  - Two variables:
    - $p_T^*$  and  $m_{miss}^2 = (P_{ee} - P_{Btag} - P_{D^{(*)}} - P_l)^2$ .
  - Fitted yields in each of the 4 channels ( $D^0$ ,  $D^+$ ,  $D^{*0}$ ,  $D^{*+}$ ):
    - $D^{(*)} \tau \nu$  signal,
    - $D^{(*)} l \nu$  normalization,
    - $D^{**} l \nu$  background,
  - Fixed from data: cross-feed, combinatorial, and continuum.

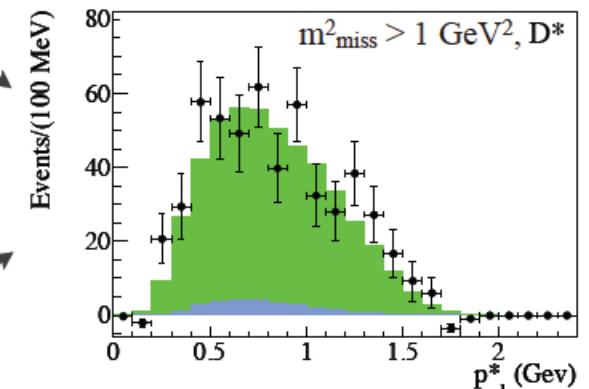
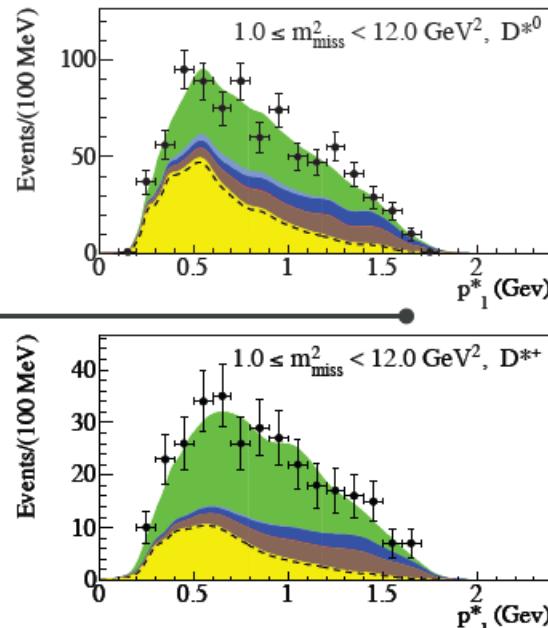
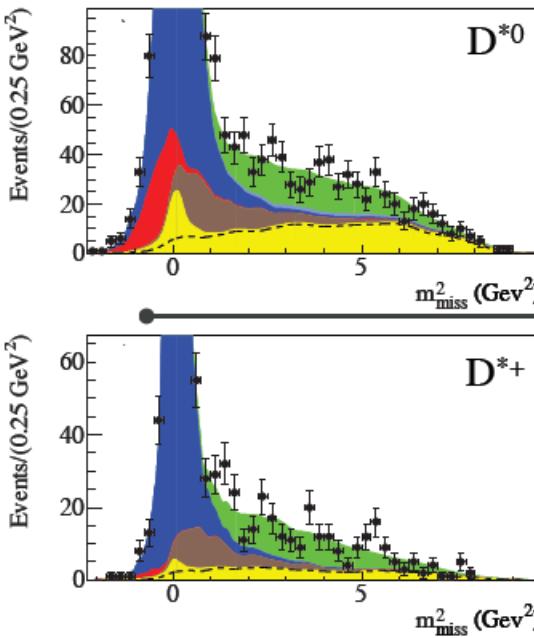
# B $\rightarrow$ D\* $\tau \nu$ : fit results

- Good fit agreement
- Uncertainties statistical

Free in the fit   
 {  
█ D\* $\tau\nu$   
█ D $\tau\nu$   
█ D\* $l\nu$   
█ D $l\nu$   
█ D\*\* $l\nu$   
█ Bkg.  
 Fixed

	D* $^0\tau\nu$	D* $^+\tau\nu$	D* $\tau\nu$
N <sub>sig</sub>	639 $\pm$ 62	245 $\pm$ 27	888 $\pm$ 63
Signif.	11.3 $\sigma$	11.6 $\sigma$	16.4 $\sigma$
R(D*)	<b>0.322 <math>\pm</math> 0.032</b>	<b>0.355 <math>\pm</math> 0.039</b>	<b>0.332 <math>\pm</math> 0.024</b>

Isospin constrained



D\*⁰ and D\*⁺ channels combined.  
Background subtracted

# B $\rightarrow$ D $\tau \nu$ : fit results

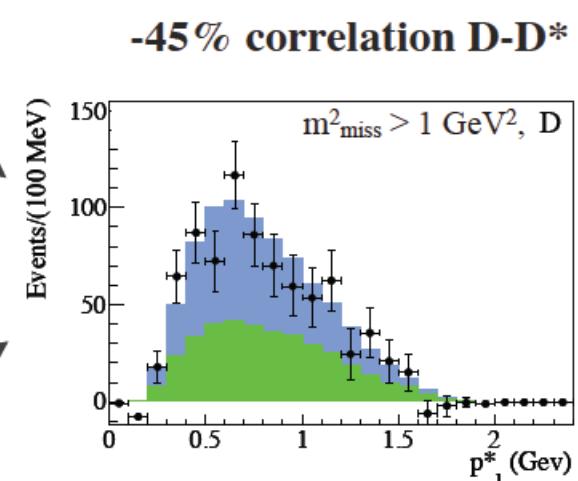
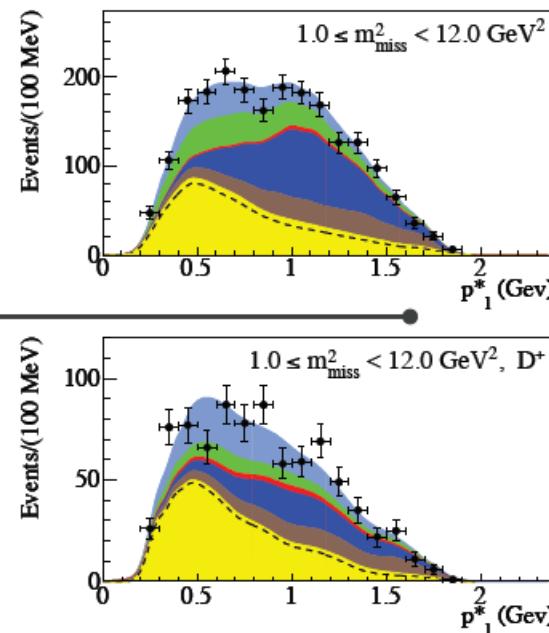
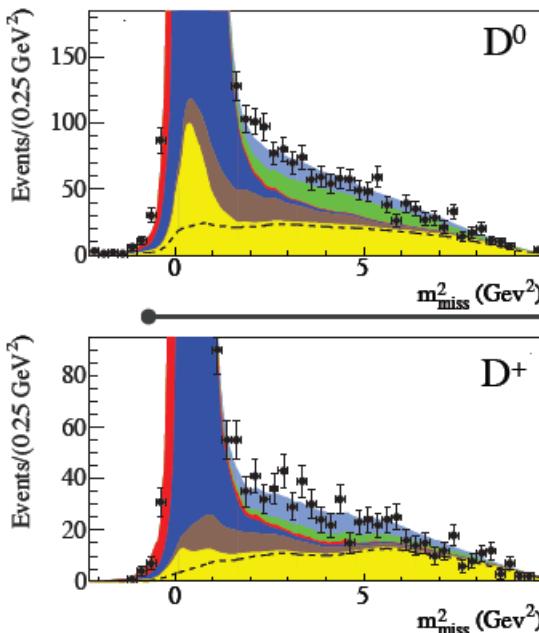
- First  $5\sigma$  observation
- Uncertainties statistical

Free in the fit   
  
 Fixed

First observation!

	D <sup>0</sup> $\tau\nu$	D <sup>+</sup> $\tau\nu$	D $\tau\nu$
N <sub>sig</sub>	314 $\pm$ 60	177 $\pm$ 31	489 $\pm$ 63
Signif.	5.5 $\sigma$	6.1 $\sigma$	8.4 $\sigma$
R(D)	0.429 $\pm$ 0.082	0.469 $\pm$ 0.084	0.440 $\pm$ 0.058

Isospin constrained

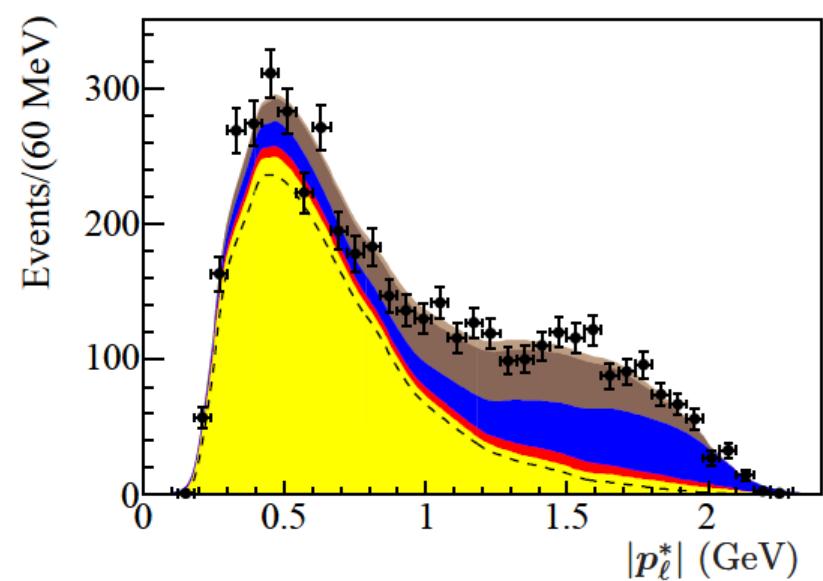
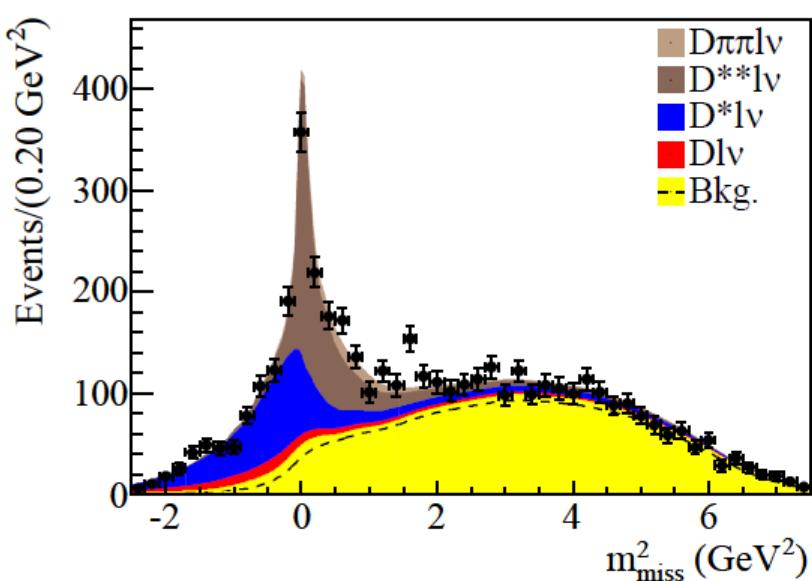


D<sup>0</sup> and D<sup>+</sup> channels combined.  
Background subtracted

# $B \rightarrow D^{(*)} \tau \nu$ : systematic uncertainties

- Largest syst. due to backgrounds
- Small uncertainty on efficiency ratio  $\epsilon_{\text{sig}}/\epsilon_{\text{norm}}$
- Statistical uncertainty dominates
- D $^{**}$  lv background checked with  
D $^{(*)}$   $\pi^0$  lv control samples

Source	Uncertainty (%)	$R(D)$	$R(D^*)$	$\rho$
$D^{**}\ell\nu$ background	5.8	3.7	0.62	
MC statistics	5.0	2.5	-0.48	
Cont. and $B\bar{B}$ bkg.	4.9	2.7	-0.30	
$\epsilon_{\text{sig}}/\epsilon_{\text{norm}}$	2.6	1.6	0.22	
Systematic uncertainty	9.5	5.3	0.05	
Statistical uncertainty	13.1	7.1	-0.45	
Total uncertainty	16.2	9.0	-0.27	

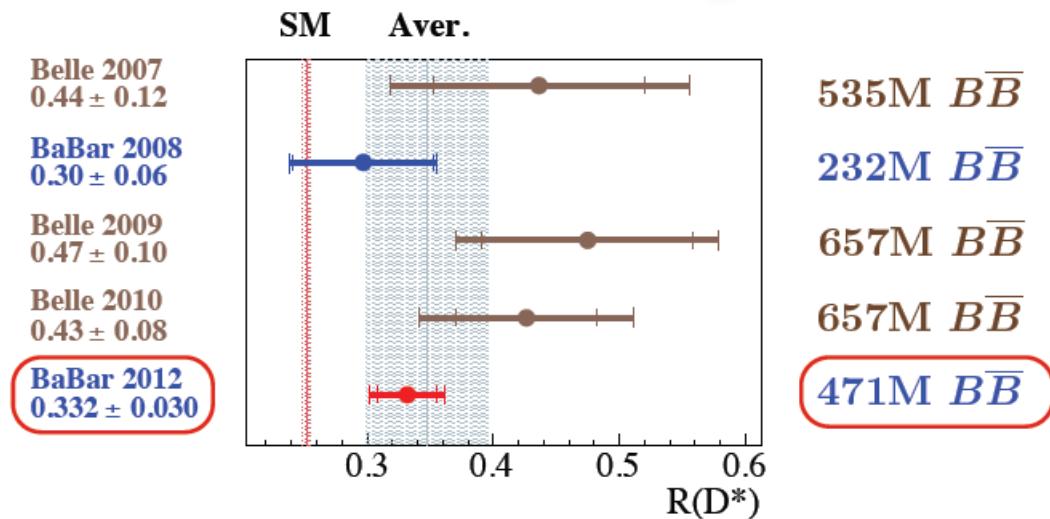
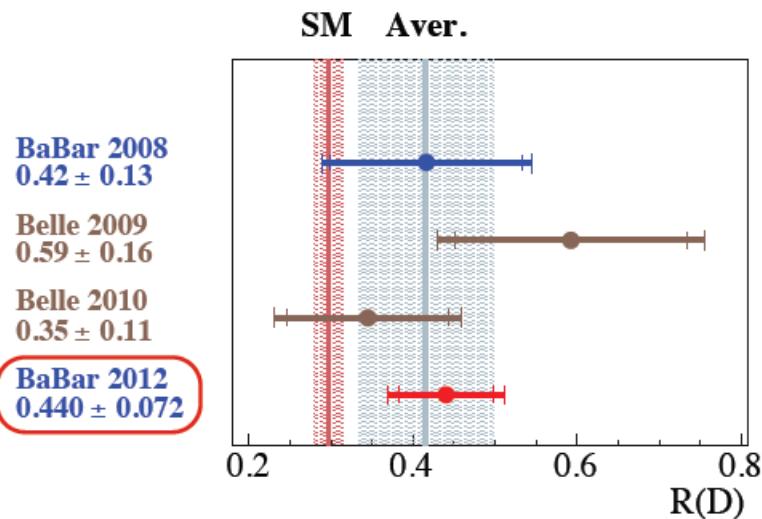


# $B \rightarrow D^{(*)} \tau \nu$ : results and comparison to previous measurements

Decay	$N_{\text{sig}}$	$N_{\text{norm}}$	$R(D^{(*)})$	$\mathcal{B}(B \rightarrow D^{(*)}\tau\nu) (\%)$	$\Sigma_{\text{tot}}(\sigma)$
$D\tau^-\bar{\nu}_\tau$	$489 \pm 63$	$2981 \pm 65$	$0.440 \pm 0.058 \pm 0.042$	$1.02 \pm 0.13 \pm 0.11$	6.8
$D^*\tau^-\bar{\nu}_\tau$	$888 \pm 63$	$11953 \pm 122$	$0.332 \pm 0.024 \pm 0.018$	$1.76 \pm 0.13 \pm 0.12$	13.2

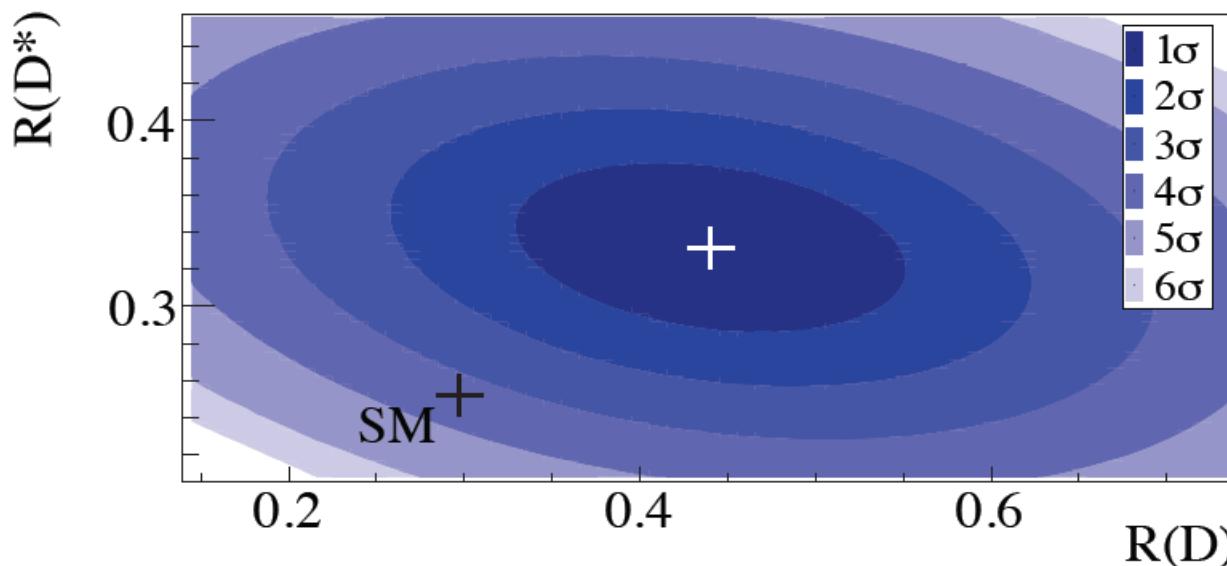
- First  $5\sigma$  observation of  $B \rightarrow D\tau\nu$
- Agreement with previous measurements

Average does not include this analysis



# $B \rightarrow D^{(*)} \tau \bar{\nu}$ : comparison with SM

$$R(D) = \left\{ \begin{array}{ll} 0.440 \pm 0.072 & BABAR \\ 0.297 \pm 0.017 & \text{SM} \end{array} \right\} \quad 2.0\sigma$$
$$R(D^*) = \left\{ \begin{array}{ll} 0.332 \pm 0.030 & BABAR \\ 0.252 \pm 0.003 & \text{SM} \end{array} \right\} \quad 2.7\sigma$$
$$\left. \right\} 3.4\sigma$$

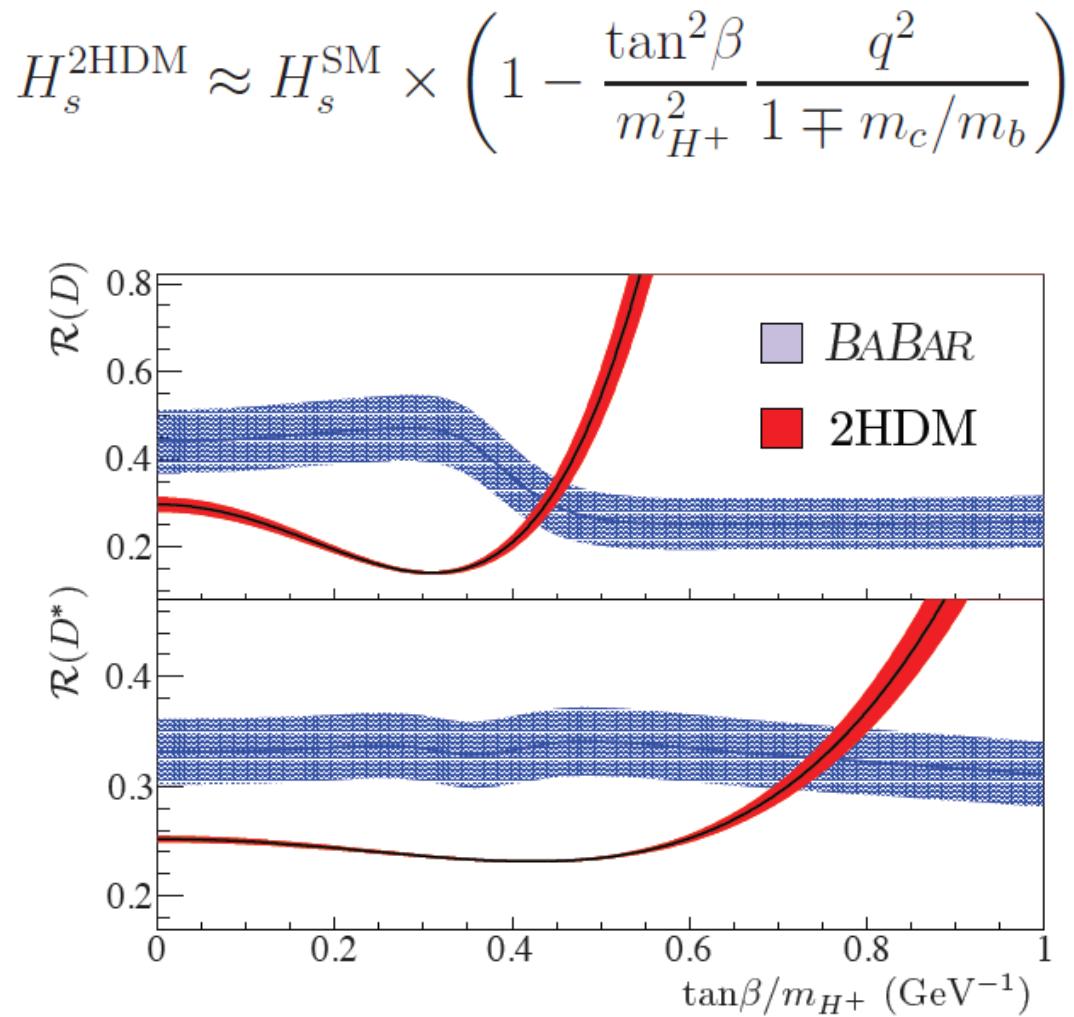


**$R(D)$  and  $R(D^*)$  not independent**

**-27% correlation**

# B → D(\*) τ ν : 2HDM

- A charged Higgs of spin 0 will affect  $H_s$  and modify  $R(D^{(*)})$ .
- Data match 2HDM type II at
  - $\tan\beta/m_H = 0.44 \pm 0.02$  for  $R(D)$
  - $\tan\beta/m_H = 0.75 \pm 0.04$  for  $R(D^*)$
- Combination excludes 2HDM type II with a probability greater than 99.8% provided  $m_H > 10$  GeV.



# Conclusion

- Updated result on

$$B(B \rightarrow \tau \nu) = (1.83^{+0.53}_{-0.49} \pm 0.24) \cdot 10^{-4}.$$

- Improved measurement of the ratios of  $B(B \rightarrow D^{(*)}\tau\nu)$  over  $B(B \rightarrow D^{(*)}\bar{\nu})$ .
  - $R(D) = 0.440 \pm 0.058 \pm 0.042$ ,
  - $R(D^*) = 0.332 \pm 0.024 \pm 0.018$ ,
  - Evidence for a  $3.4\sigma$  excess with respect to the SM expectations.
  - 2HDM type II cannot accommodate the results.