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

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Introduction

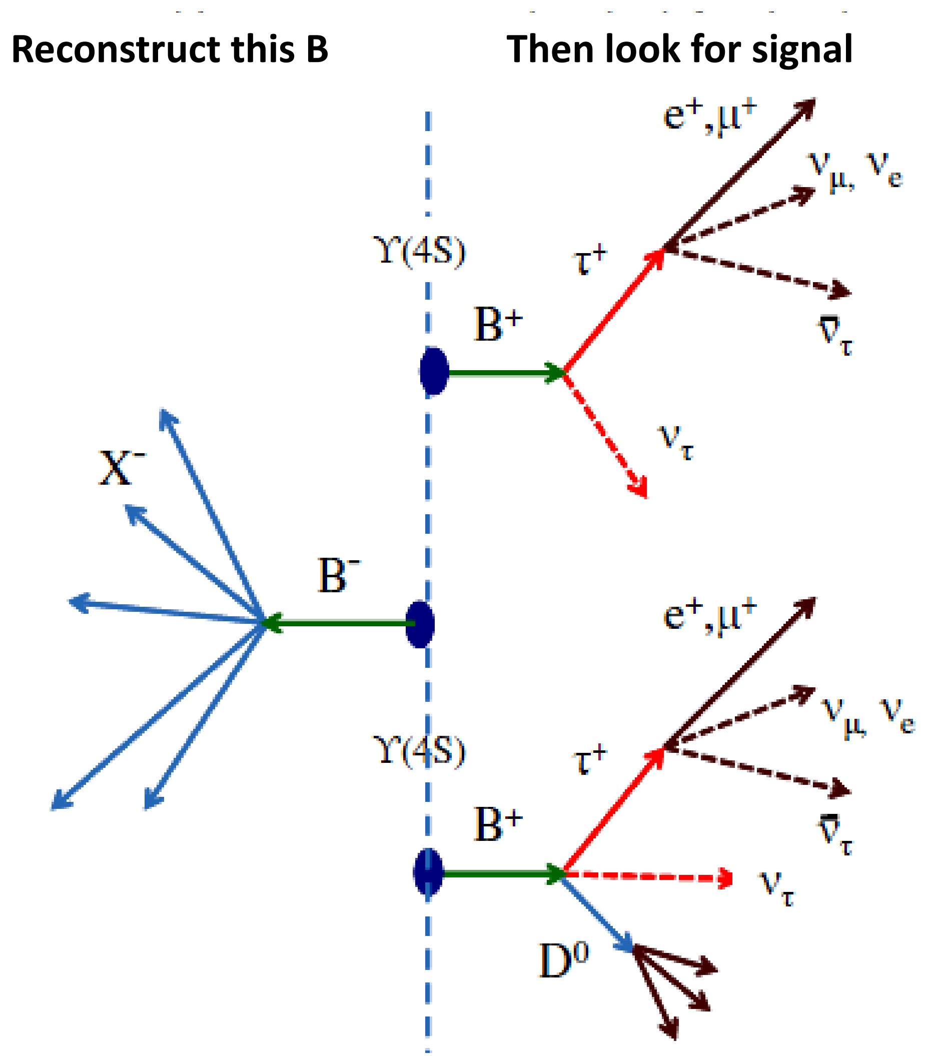
- $B \to D^{(*)}\tau\,\nu$ and $B \to \tau\,\nu$ decays are of particular interest to test the predictions of the Standard Model and to search for New Physics effects.

- The analyses presented in this talk use the full BaBar data set of 4.7×10^6 BB pairs.

- Both analyses take advantage of the B tagging method.

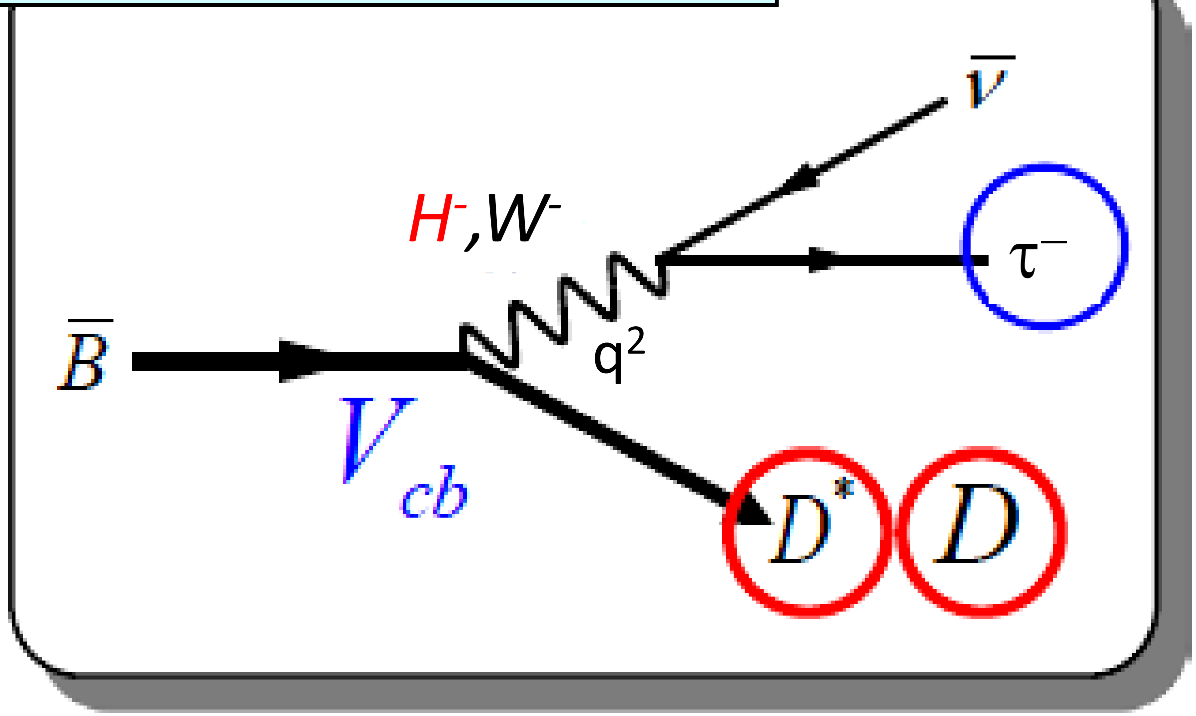
B Tagging Method

- Difficult signal signature:
  - Many neutrinos in final state.
  - Lack of kinematical constraints.
- Reconstruction of companion B in semileptonic or hadronic decay modes improve background rejection.
- Look for signal in the rest of the event
  - Expect to find nothing more than visible signal decay products.
  - No additional track or activity in the calorimeter.



arXiv:1205.5442 [hep-ex], submitted to Phys.Rev.Lett.

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



Ratio of $B \to D^{(*)}\tau\,\nu$ vs $B \to D^{(*)}\, l\, \nu$ Decays

- Semileptonic decays with a τ have an additional helicity amplitude.
- Fo r $B \to D^{*}\tau\,\nu$:

$$\frac{d\Gamma_\tau}{dq^2} = \frac{G_F^2|V_{cb}|^2|\mathrm{p}|q^2}{96\pi^3 m_B^2}\left(1-\frac{m_\tau^2}{q^2}\right)^2\left[\left(|H_{++}|^2+|H_{--}|^2+|H_{00}|^2\right)\left(1+\frac{m_\tau^2}{2q^2}\right)+\frac{3}{2}\frac{m_\tau^2}{q^2}|H_{0t}|^2\right]$$

- Only H_{00} and H_{0t} contributes to $B \to D\tau\,\nu$
- To test standard model prediction we measure:

$$R(D) = \frac{\Gamma(\overline{B} \to D\tau\nu)}{\Gamma(\overline{B} \to D\ell\,\nu)} \qquad R(D^*) = \frac{\Gamma(\overline{B} \to D^*\tau\nu)}{\Gamma(\overline{B} \to D^*\ell\,\nu)} \qquad \ell = e,\mu$$

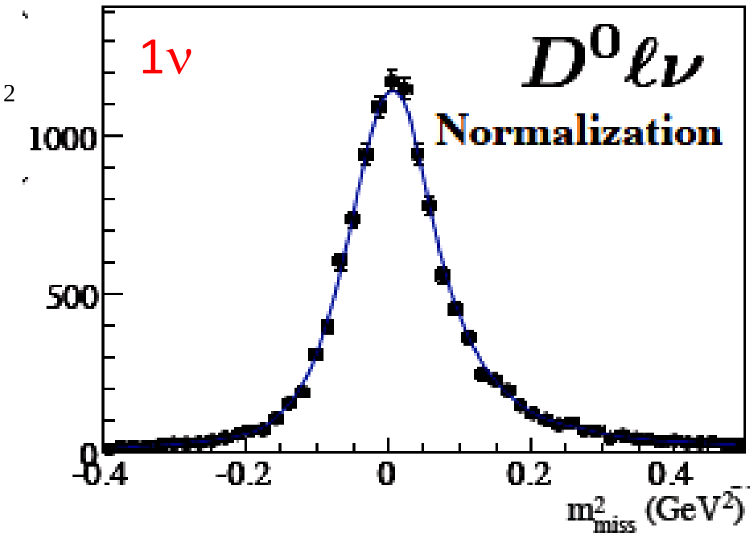
  - Several experimental and theoretical uncertainties cancel in the ratio
  - Sensitive to contribution from new physics
  - For example to charged Higgs

Analysis Strategy

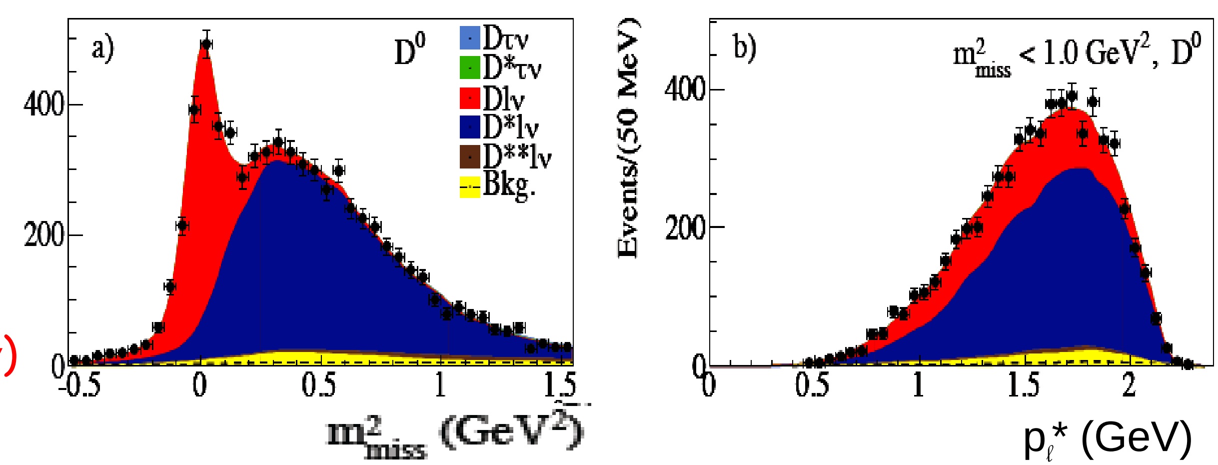
- Full reconstruction of B_{tag} in its hadronic decays.
  - B_{tag} efficiency improved and extended to low momentum.
- In the rest of the event:
  - Identify an e or a μ
    - from τ decay in the $B \rightarrow D^{(*)}\tau\nu$ signal sample
    - Directly from B decay in the $B \rightarrow D^{(*)}l\nu$ (l=e,μ) normalization sample
  - Reconstruct a D candidate (D^{*0}, D^{*+}, D^0, D^+).
  - No additional reconstructed tracks
  - Kinematical requirement: $q^2 > 4$ GeV^2
  - Use BDT to suppress background (combinatorial and $D^{**}l\nu$)
- Unbinned Maximum Likelihood Fit to extract event yields.

Extraction of Yields from M.L. Fit

- 2D Unbinned M.L. fit to:
  - Missing Mass sq: $m^2_{miss} = (P_{ee} - P_{Btag} - P_{D(*)} - P_\ell)^2$
  - Lepton momentum in B rest frame: p^*_ℓ
  - 4 signal samples D^0l, $D^{*0}l$, D^+l, $D^{*+}l$, ($e^\pm$ or $\mu^\pm$)
  - 4 $D^{(*)}\pi^0 l\nu$ Control samples
- PDFs from MC (approximated using Keys fct.)
- Fitted Yields
  - 4 $D^{(*)}\tau\nu$ Signal
  - 4 $D^{(*)} l\nu$ Normalization
  - 4 $D^{**} l\nu$ Backgrounds
- Fixed Backgrounds
  - B^0-B^+ cross feed
  - BB combinatorial BG
  - Continuum $e^+e^- \to f\ f(\gamma)$



MC Simulation

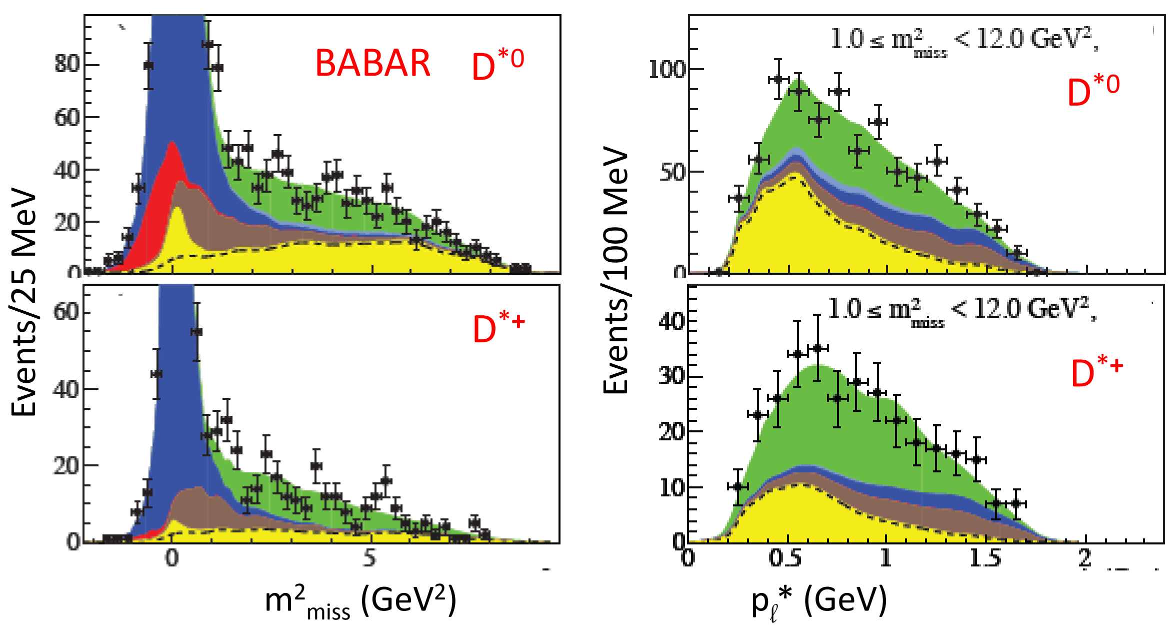


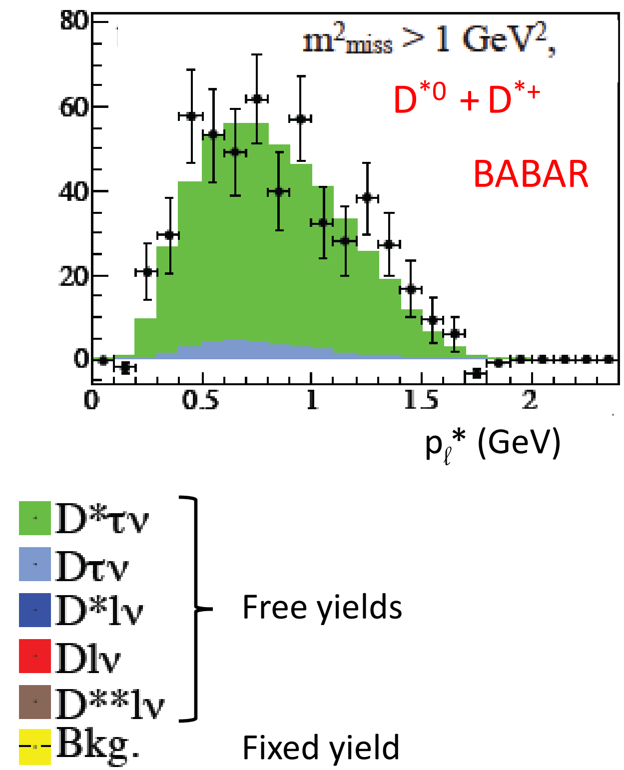
Results of Fit: $B \to D^* \tau \nu$

Isospin constrained

	$D^{*0}\tau\nu$	$D^{*+}\tau\nu$	$D^{*}\tau\nu$
N_{sig}	639 ± 62	245 ± 27	888 ± 63
Significance (σ)	11.3	11.6	16.4
$R(D^*)$	0.322 ± 0.032	0.355 ± 0.039	0.332 ± 0.024

Statistical errors only



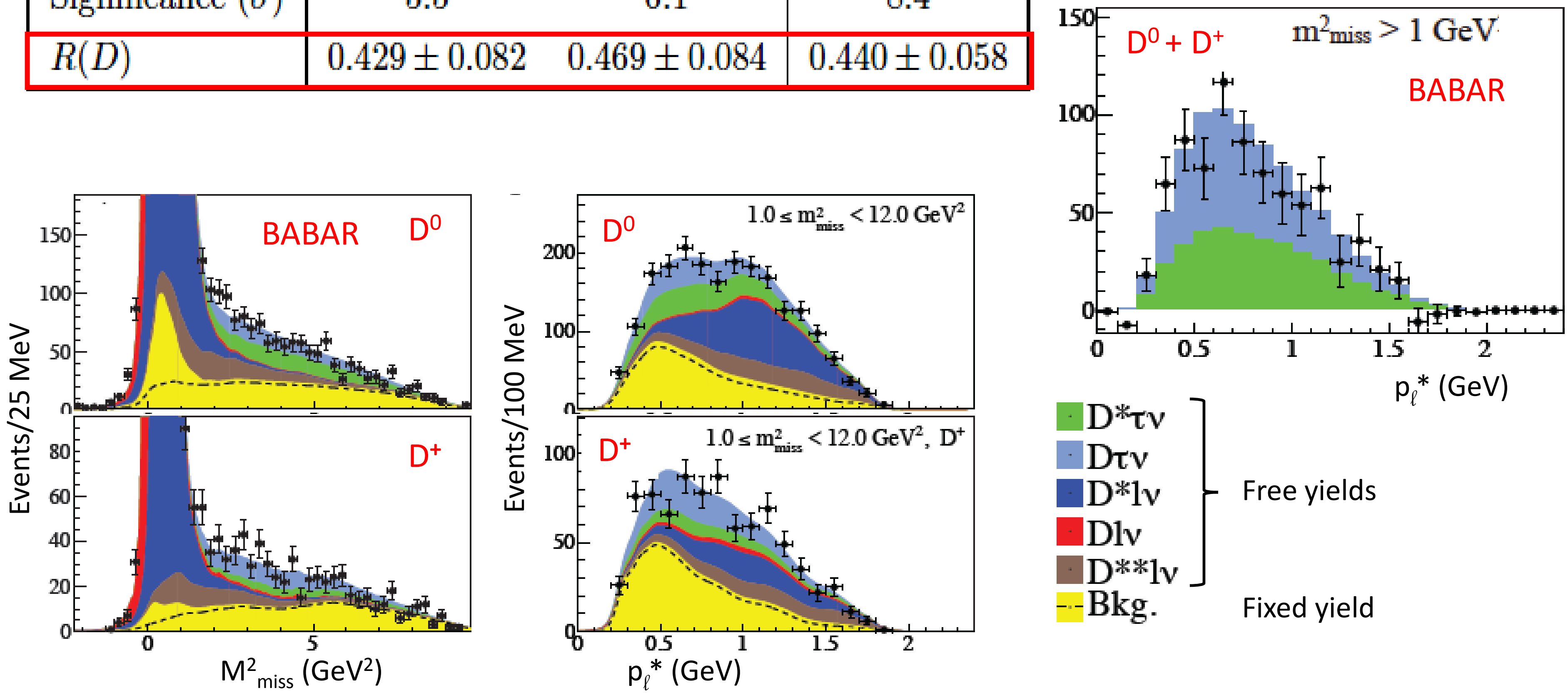


Results of Fit: B→Dτν

Isospin constrained

	$D^0\tau\nu$	$D^+\tau\nu$	$D\tau\nu$
$N_{\rm sig}$	314 ± 60	177 ± 31	489 ± 63
Significance (σ)	5.5	6.1	8.4
$R(D)$	0.429 ± 0.082	0.469 ± 0.084	0.440 ± 0.058

Statistical errors only



Systematic Uncertainties

ρ Correlation between R(D) and R(D*)

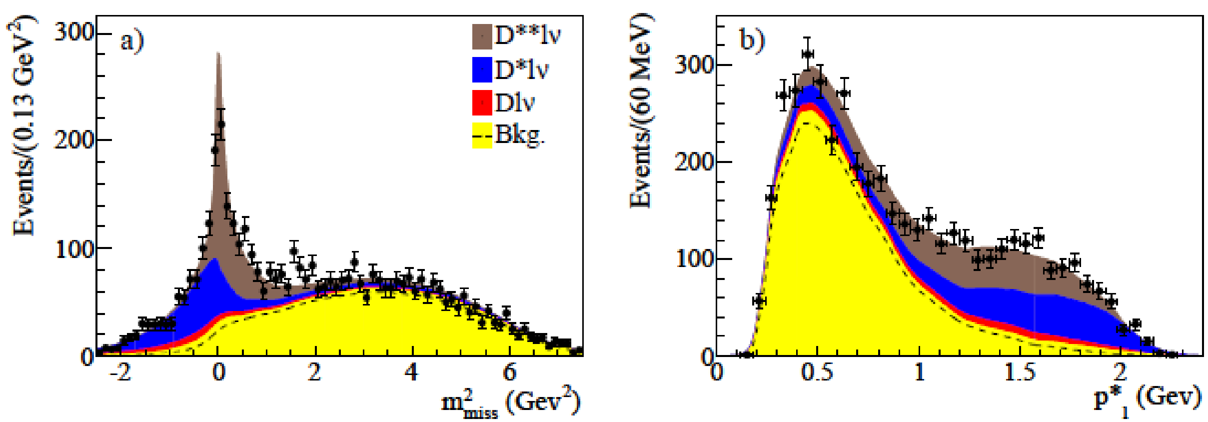
Principal Uncertainties:

- $D^{**} l \nu$: conservative 15%
  constraints and fit to Dπ sample,
- Limited MC signal samples
  2-dim PDFs with ~2000 events per bin
- Continuum and BB background
  Corrections and MC statistics

Source	Uncertainty (%) $R(D)$	Uncertainty (%) $R(D^*)$	ρ
$D^{**}\ell\nu$ background	5.8	3.7	0.62
MC statistics	5.0	2.5	-0.48
Cont. and $B\overline{B}$ bkg.	4.9	2.7	-0.30
$\varepsilon_{sig}/\varepsilon_{norm}$	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

Largest systematic errors are Gaussian distributed!
Results of fit to $D^{**} l \nu$ control sample for the sum of the 4 channels:
$D^0\pi^0 l\nu$, $D^{*0}\pi^0 l \nu$,
$D^+\pi^0 l\nu$, $D^{*+}\pi^+ l \nu$

$D\pi^0$ l ν Control Sample



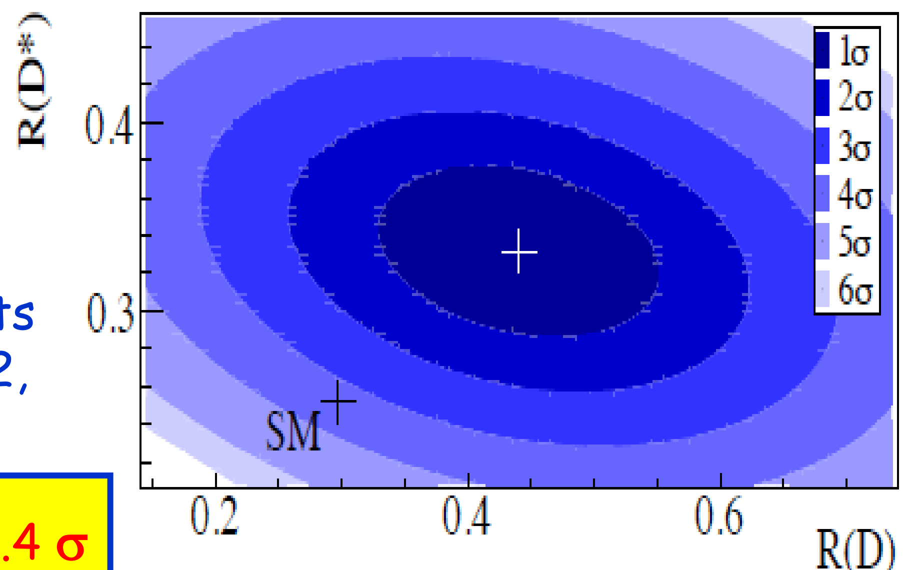
Summary of R(D) and R(D*) Measurements

Decay	N_{sig}	N_{norm}	$R(D^{(*)})$	$\mathcal{B}(B \to D^{(*)}\tau\nu)$ (%)	$\Sigma_{tot}(\sigma)$
$D^0\tau^-\overline{\nu}_\tau$	314 ± 60	1995 ± 55	$0.429 \pm 0.082 \pm 0.052$	$0.99 \pm 0.19 \pm 0.13$	4.7
$D^{*0}\tau^-\overline{\nu}_\tau$	639 ± 62	8766 ± 104	$0.322 \pm 0.032 \pm 0.022$	$1.71 \pm 0.17 \pm 0.13$	9.4
$D^+\tau^-\overline{\nu}_\tau$	177 ± 31	986 ± 35	$0.469 \pm 0.084 \pm 0.053$	$1.01 \pm 0.18 \pm 0.12$	5.2
$D^{*+}\tau^-\overline{\nu}_\tau$	245 ± 27	3186 ± 61	$0.355 \pm 0.039 \pm 0.021$	$1.74 \pm 0.19 \pm 0.12$	10.4
$D\tau^-\overline{\nu}_\tau$	489 ± 63	2981 ± 65	$0.440 \pm 0.058 \pm 0.042$	$1.02 \pm 0.13 \pm 0.11$	6.8
$D^*\tau^-\overline{\nu}_\tau$	888 ± 63	11953 ± 122	$0.332 \pm 0.024 \pm 0.018$	$1.76 \pm 0.13 \pm 0.12$	13.2

Comparison with SM calculation:

	R(D)	R(D*)
BABAR	0.440 ± 0.071	0.332 ± 0.029
SM	0.297 ± 0.017	0.252 ± 0.003
Difference	**2.0 σ**	**2.7 σ**

BABAR

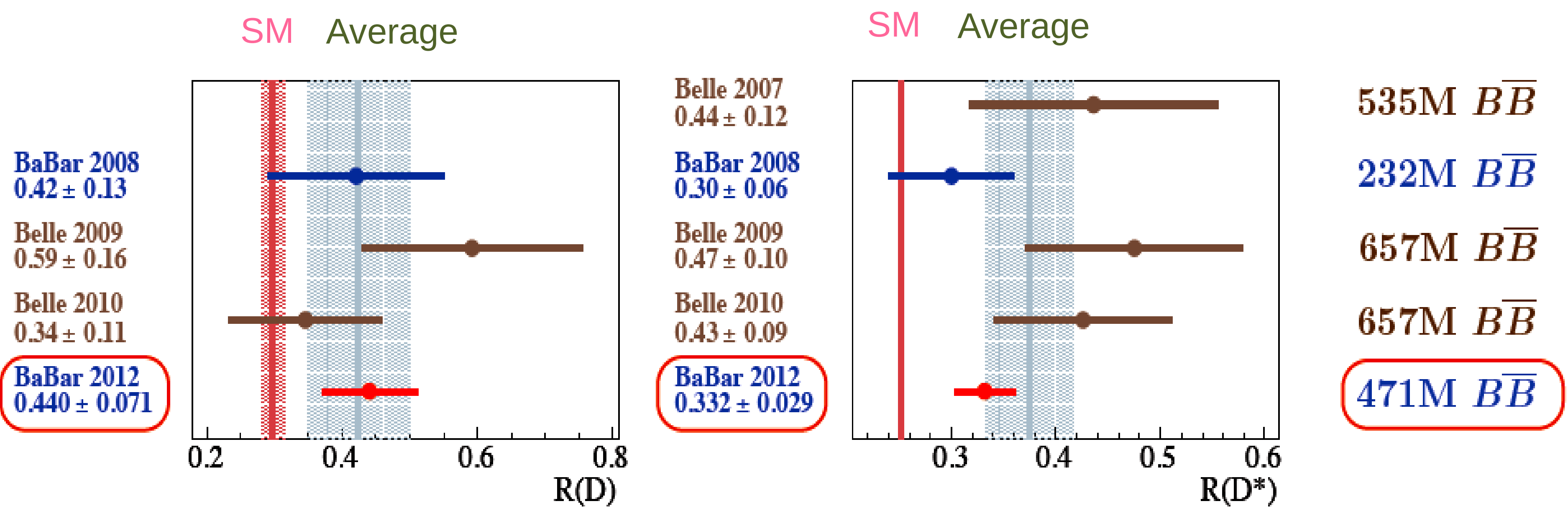


The combination of the two measurements (-0.27 correlation) yields χ^2/NDF=14.6/2, i.e. Prob. = 6.9×10^{-4} !!

Thus the SM prediction is excluded at 3.4 σ

Comparison to Previous Measurements

NB: Average does not include this measurement



The new measurements are fully compatible with earlier results!

Can we explain the excess events?

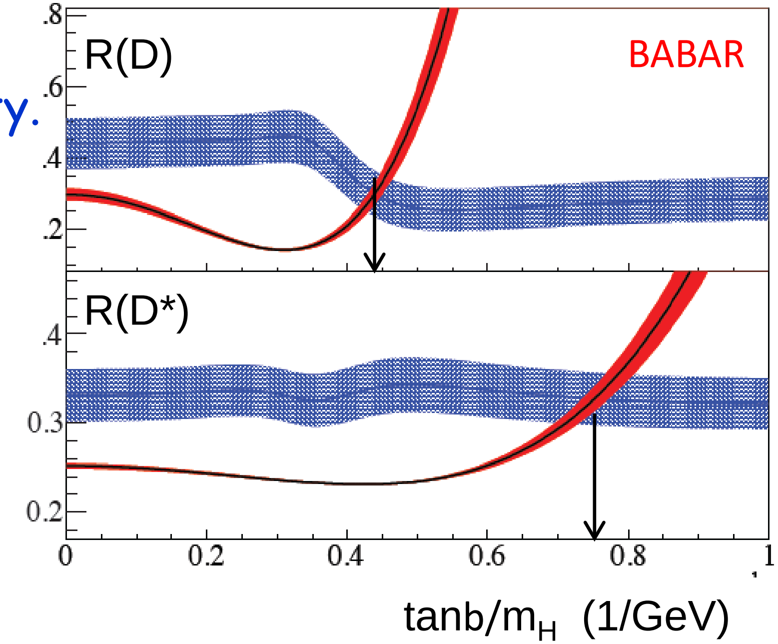
- A charged Higgs (2HDM type II) of spin 0 coupled to the τ will only affect H_t

$$H_t^{2HDM} = H_t^{SM} \times \left(1 - \frac{\tan^2\beta}{m_{H\pm}^2} \frac{q^2}{1 \mp m_c/m_b}\right)$$

- for $D\tau\nu$
+ for $D^*\tau\nu$

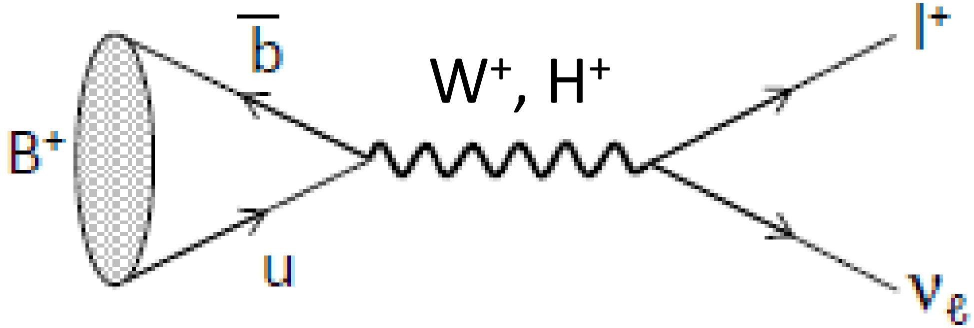
This could enhance or decrease the ratios R(D*) depending on $\tan\beta/m_H$

- We estimate the effect of 2DHM, accounting for difference in efficiency, and its uncertainty.
- The data match 2DHM 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*)
- However, the combination of R(D) and R(D*) excludes the Type II 2HDM in the full $\tan\beta$-m_H parameter space with a probability of >99.8%, provided M_H>10GeV !



arXiv:1207.0698 [hep-ex], submitted to Phys.Rev.D RC

B-> $\tau\nu$



Leptonic B Decays

- $B \to l\nu$ decays are very clean theoretically. The only uncertainties are in the B decay constant f_B and in $|V_{ub}|$.

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

- Interesting probe of physics beyond the SM, since also a charged Higgs can mediate the decay.

$$\mathcal{B}(B \to l\nu)_{2HDM} = \mathcal{B}(B \to l\nu)_{SM} \times (1 - tan^2\beta \frac{m_B^2}{m_H^2})^2$$

- $B \to \mu\nu$ and $B \to e\nu$ are out of reach at B Factories.

- $B \to \tau\nu$ measurements are already excluding regions of the m_H – $\tan\beta$ plane.

Analysis Strategy

- Full reconstruction of B_{tag} in its hadronic decays.
- In the rest of the event:
  - "Reconstruct" τ from $\tau \to e, \mu, \pi, \rho\ \nu$ decays (72% of τ BF).
    - Two or more neutrinos in the event.
    - Only a single charged track .
    - No residual energy in the calorimeter.
- E_{extra} is the most powerful discriminating variable.
  - Defined as the total energy of clusters passing a minimum energy requirement.
  - E_{extra} distribution validated with the use of double-tagged events.
- Maximum Likelihood Fit to E_{extra} distribution to extract branching fraction.

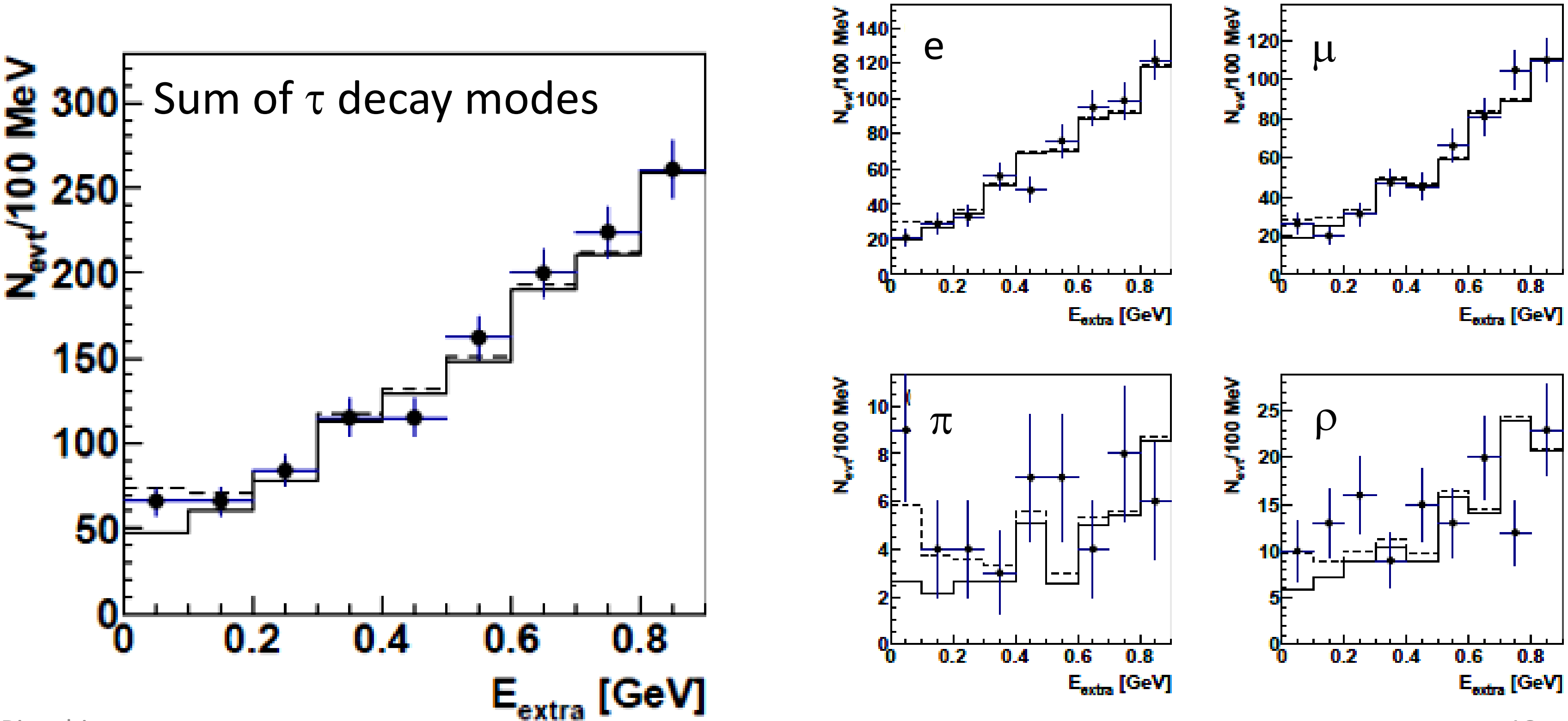
Extraction of BF from M.L. Fit

- Simultaneous fit to E_{extra} of the four τ modes, constrained to the same BF.
- Signal PDF taken from signal MC and corrected for data/MC disagreement
  - Correction for mismodeling of detector effect on E_{extra} evaluated by comparing data sidebands and background MC.
- Background PDF from
  - data sidebands (combinatory/ background)
  - B^+B^- MC (peak. component only)

Result of the Fit: B->τν

- Fit to E_{extra} distribution show an excess of events consistent with null hypothesis at 3.3 σ only.

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



Systematic Uncertainties

- Dominant systematics :
  - Background E_{extra} PDF
  - Tagged B efficiency
  - μ identification

Source of systematics	$\mathcal{B}$ uncertainty (%)
Additive	
Background PDF	10
Signal PDF	2.6
Multiplicative	
Tag-B efficiency	5.0
B counting	1.1
Electron identification	2.6
Muon identification	4.7
Kaon identification	0.4
Tracking	0.5
MC statistics	0.6
Total	13

Comparison with Previous Measurements

Experiment	Tag	Branching Fraction ($\times 10^{-4}$)
BABAR	hadronic	$1.8^{+0.9}_{-0.8} \pm 0.4 \pm 0.2$
BABAR	semileptonic	$1.7 \pm 0.8 \pm 0.2$
Belle	hadronic	$1.79^{+0.56}_{-0.49}{}^{+0.46}_{-0.51}$
Belle	semileptonic	$1.54^{+0.38}_{-0.37}{}^{+0.29}_{-0.31}$

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

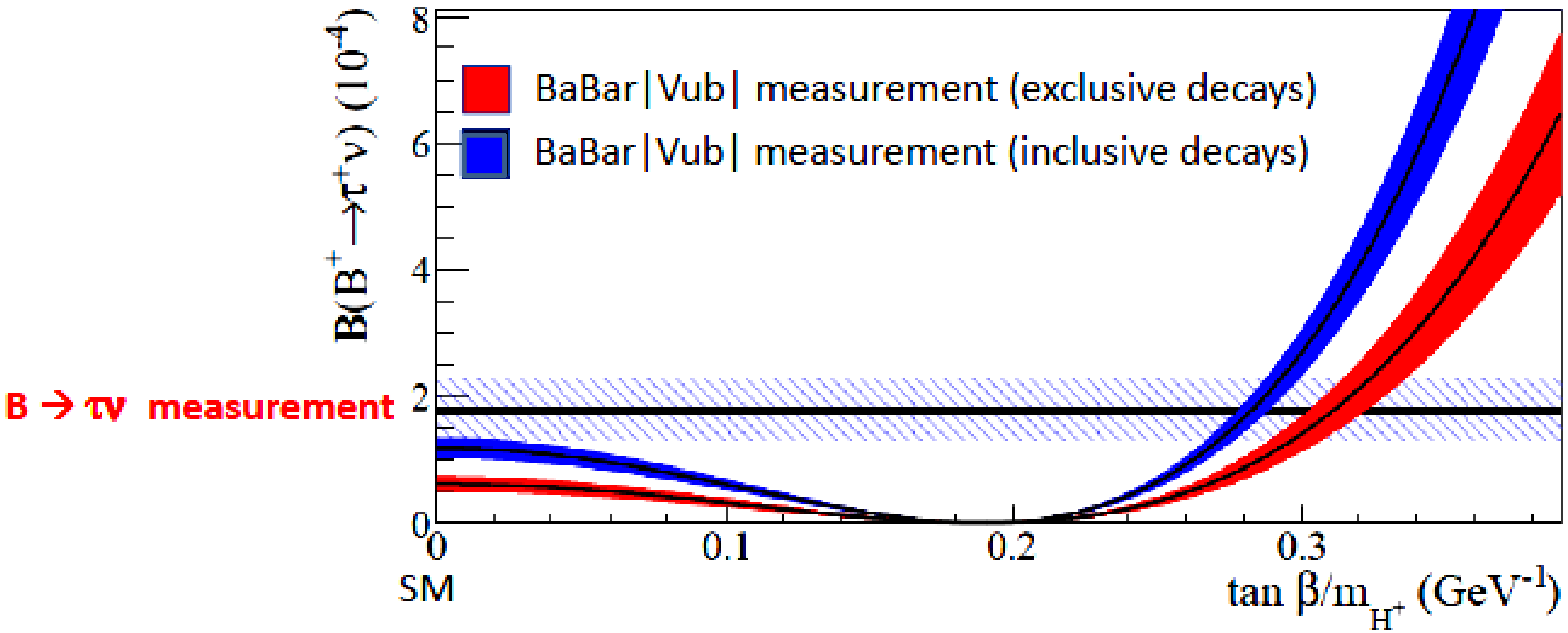
This measurement exceeds SM predictions determined using exclusive (inclusive) $|V_{ub}|$ measurement by 2.4 (1.6) σ.

Breaking News from Belle at ICHEP:

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

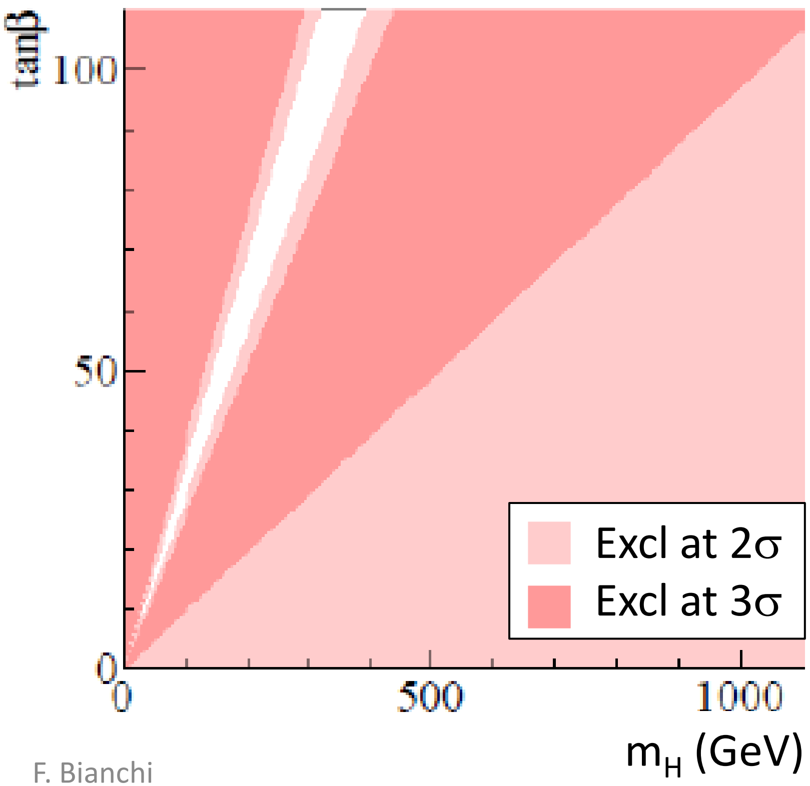
Comparison with 2HDM type II

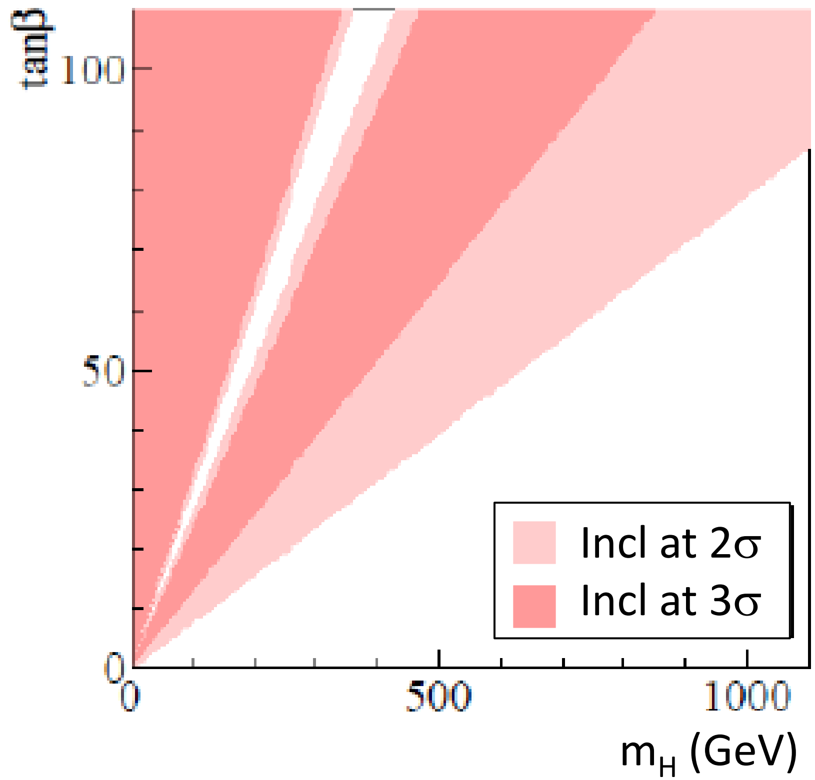
$$\mathcal{B}(B \to l\nu)_{2HDM} = \mathcal{B}(B \to l\nu)_{SM} \times (1 - tan^2\beta \frac{m_B^2}{m_H^2})^2$$



Constraints on the tanβ vs m_{H^+} plane in 2HDM type II

- Most of the parameter space of 2HDM is excluded at 90% C.L., if we use exclusive |Vub| determination.
- 90% C.L. exclusion for m_{H^+} up to 1 TeV at very high tan β (>70) using inclusive|Vub|





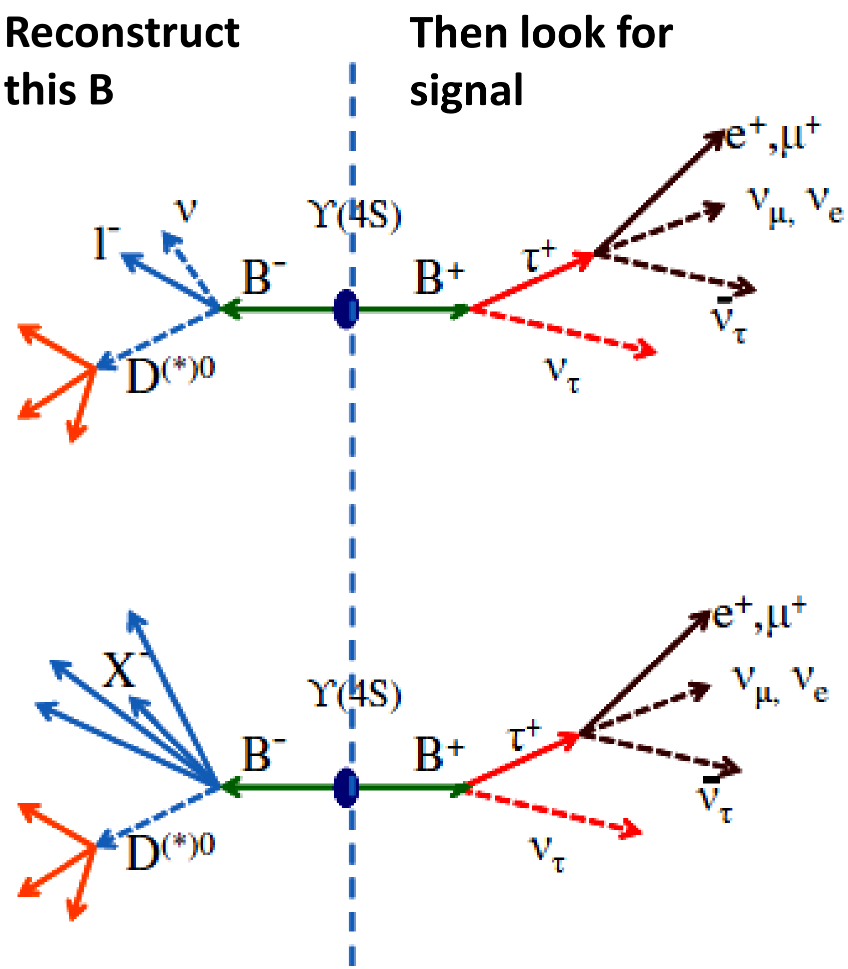
Conclusions

- Improved measurement of the ratio of the $B \to D^{(*)}\tau\nu$ branching fraction to $B \to D^{(*)}l\nu$ branching fraction.
  - There is a significant excess (3.4 σ) of events in $B \to D\tau\nu$ and $B \to D^{*}\tau\nu$ compared to the SM prediction.
  - The combination of R(D) and R(D*) excludes the Type II 2HDM in the full $\tan\beta$-m_H parameter space.
- Measurement of $B \to \tau\nu$ with hadronic tag using the full BaBar dataset.
  - Some tension with the SM (2.4 σ) when using exclusive $|V_{ub}|$ determination.
- More statistics is necessary to further investigate these decay modes.
  - We need a Super B Factory !!!

Backup

Hadronic and Semileptonic Tags

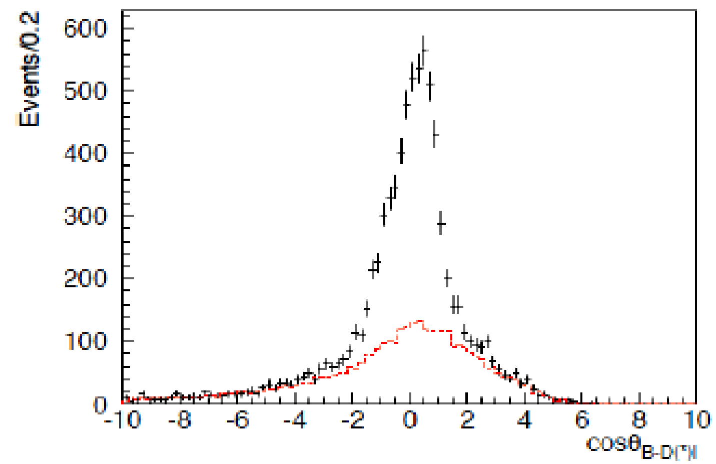
- Semileptonic B decays
  - $B \to D^* l \nu$
  - PRO: Higher efficiency
    $\varepsilon_{tag} \sim 1.5\%$
  - CON: more backgrounds, B momentum unmeasured
- Hadronic B decays with charm
  - $B+ \to D^{(*)0}X^+$ or $B^0 \to D^{(*)+}X^-$
  - X is a charged system of hadrons among (π,K,π^0,K_s) up to 5 charged particles and 2 neutrals
  - PRO: cleaner events, B momentum reconstructed
  - CON: smaller efficiency
    $\varepsilon_{tag} \sim 0.15\%$



Hadronic and Semileptonic Tags

- Semileptonic B decays
  - Recontruct the D-l pair (Y)
  - Kinematics and known B meson energy determine the angle between B and Y.

$$\cos\theta_{B,Y} = \frac{2E_B E_Y - m_B^2 - m_Y^2}{2|\vec{p}_B||\vec{p}_Y|}$$



- Hadronic B decays with charm
  - Full reconstruction of the B decay chain.
  - Requirements on the quality of the tag are analysis dependent
  - Separate the mis-reconstructed tags from correct (peaking) tags in data

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