The $B \to \tau\nu$ and $B \to \bar{D}^{(*)}\tau^{+}\nu$ measurements

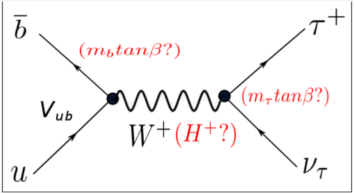
A. Bożek, INP Kraków for Belle

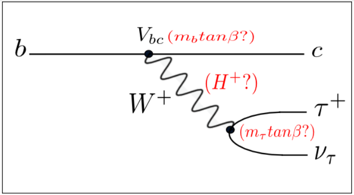
Outline

1. Introduction - Physics motivations
2. Experimental methodology
3. The $B \to \tau\nu$ measurements
4. The $B \to D^{(*)}\tau\nu$ measurements

Physics motivations

- Decays $B^+ \to \tau^+\nu$ and $B \to \overline{D}^{(*)}\tau^+\nu$ sensitive to new scalar fields (e.g. charged Higgs boson) : New Physics at the level of tree diagrams.





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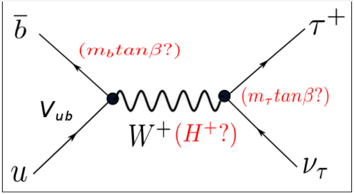

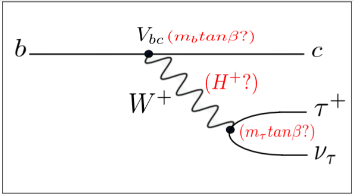

$B^+ \to \tau^+\nu$

- SM branching ratio $\mathcal{B}(B^+ \to \ell^+\nu_l) = \frac{G_F^2}{8\pi} f_{B^+}^2 |V_{ub}|^2 \tau_{B^+} M_{B^+} m_\ell^2 (1 - \frac{m_\ell^2}{M_{B^+}^2})^2$.
- Depends on: B meson decay constant f_B from lattice and $|V_{ub}|$ from measurement.
- helicity suppressed.

$B^+ \to \tau^+\nu$ - New Physics effect

- Potentially sensitive to New Physics effects
- $\mathcal{B}(B^+ \to l^+\nu_l)_{\mathrm{2HDM}} = \mathcal{B}(B^+ \to l^+\nu_l)_{\mathrm{SM}} \times r_H$
- $r_H = (1 - m_B^2 \frac{\tan^2\beta}{m_{H^+}^2})^2$.

Physics motivations

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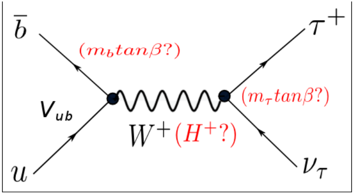
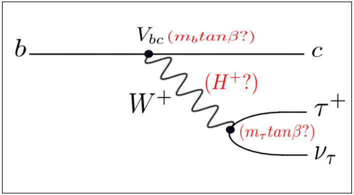




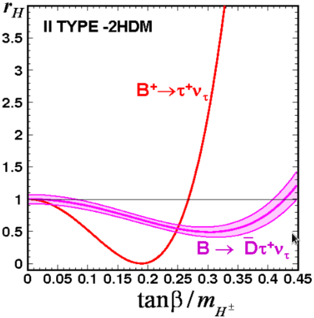
$B \to \overline{D}^{(*)}\tau^+\nu$

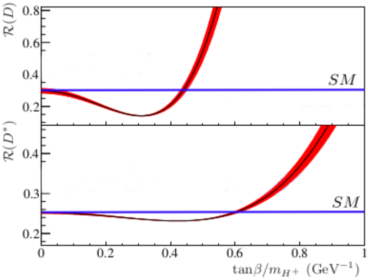
- larger numbers of observable in respect to $B^+ \to \tau^+\nu$
- new observable: τ and D^* polarization, q^2 distributions, lepton momentum.
- relatively small hadronic uncertainties (few % in SM frame)

R - BF ratios

$$R(D^{(*)}) \equiv \frac{\mathcal{B}(B\to\bar{D}^{(*)}\tau^+\bar{\nu}_\tau)}{\mathcal{B}(B\to\bar{D}^{(*)}\ell^+\bar{\nu}_\ell)}$$

$B^+ \to \tau^+\nu$ and $B \to \overline{D}^{(*)}\tau^+\nu$ decays in 2HDM-II





$$\mathcal{B} = \mathcal{B}\big|_{SM} \times r_H$$

$$r_H^{B\to\tau\nu} = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2 \qquad r_H^{B\to\bar{D}^{(*)}\tau\nu} = R/R_{SM} = 1 + 1.5Re(C_{NP}^\tau) + 1.1|C_{NP}^\tau|^2$$

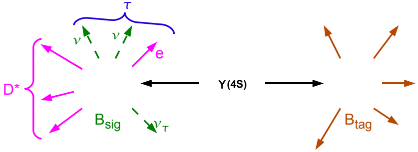
$$C_{NP}^\tau = -\frac{m_b m_\tau}{m_{H\pm}^2}\frac{tan^2\beta}{1+\varepsilon_0 tan\beta}$$

The $B \to \tau\nu$ and $B \to \bar{D}^{(*)}\tau\nu$ are sensitive to different range of $tan\beta/m_{H\pm}$

W. S. Hou, PRD **48**, 2342 (1993)
J.F. Kamenik, F.Mescia, PRD **78**, 014003 (2008)

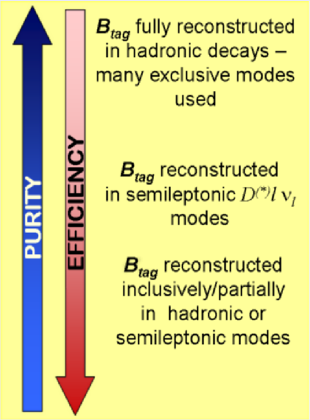
Experimentally challenging

B factories: $e^+e^- \to \Upsilon(4S) \to B\overline{B}$



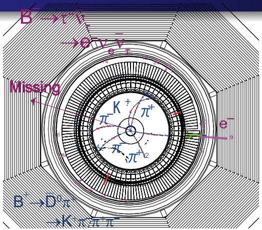
- The reconstruction of $B_{tag} \to$ tags a $B\overline{B}$ events $\to$ reduce combinatorial and continuum($q\overline{q}$, $q = u, d, s, c$) backgrounds.
- The reconstructed B_{tag} allows us to obtain kinematics constraints on $B_{sig}(B \to D^{(*)}\tau\nu)$ momentum: $\vec{p}_{sig} = -\vec{p}_{tag} \Rightarrow p_B$
- small reconstruction efficiency (below 10^{-2})

Different approach for B_{tag} reconstructions

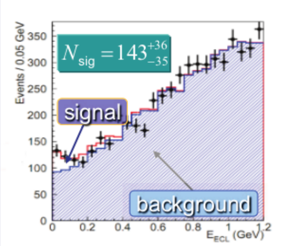


$\to B_{tag}$ momentum resolution

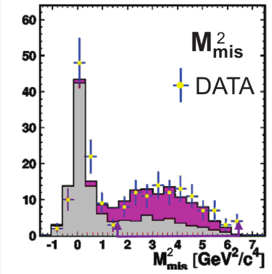
B_{sig} reconstruction



E_{ECL} - Extra energy in the calorimeter (Energy left over after B_{sig} and B_{tag} reconstruction)



$MM2$ - missing mass square



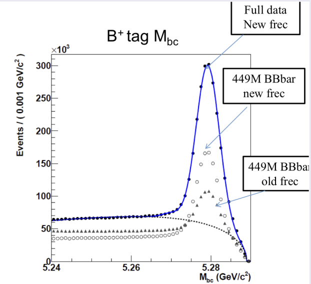
Exclusive analysis $\rightarrow$ Signal extraction from signal side variable. - historic nomenclature used in that talk.

K. Hara *et al.*, [Belle Collaboration], Phys. Rev. D **82**, 071101 (2010)
A. Matyja *et al.*, [Belle Collaboration], Phys. Rev. Lett. **99**, 191807 (2007), M.Rozanska, "Studies of B decays with missing energy", SUSY07

Exclusive B_{tag} reconstruction

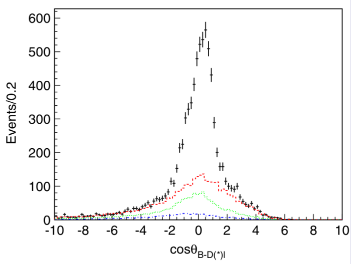
First we find an event with reconstructed B_{tag} then we check if the rest of the tracks are consistent with signal hypothesis.

Hadronic decay tags:
$B_{tag} \to D^{(*)}X(X = \pi, \rho, D_s, \ldots)$



$$M_{bc} = \sqrt{E_{beam}^2 - \mathbf{p}^2}$$
$$\Delta E = E - E_{beam}$$

Semileptonic decay tags:
$B_{tag} \to D^{(*)}\ell\nu_\ell$



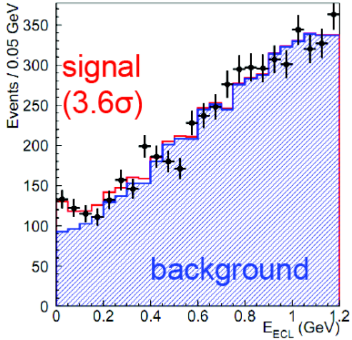
$$cos\theta_{B,D^{(*)}\ell} = \frac{2E_{beam}^{cms}E_{D^{(*)}\ell}^{cms} - m_B^2 - M_{D^{(*)}\ell}^2}{2P_B^{cms}.P_{D^{(*)}\ell}^{cms}}$$

$B^+ \to \tau^+\nu$ measurements

$B^+ \to \tau^+\nu$ by semileptonic tag

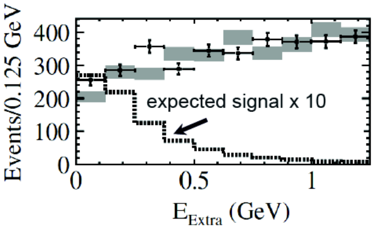
Belle

- based on 657 M $B\bar{B}$
- $\mathcal{B} = (1.54^{+0.38}_{-0.37}{}^{+0.29}_{-0.31}) \times 10^{-4}$



BABAR

- based on 459 M $B\bar{B}$,
- counting method used,
- $\mathcal{B} = (1.7 \pm 0.8 \pm 0.2) \times 10^{-4}$.

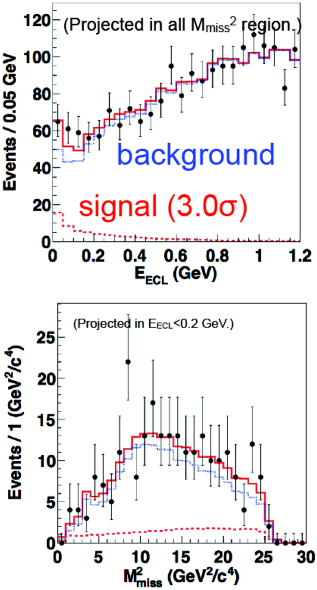


Belle PRD 82, 071101(R) (2010)
BABAR PRD 81, 051101(R) (2010)

$B^+ \to \tau^+\nu$ by hadronic tag - Belle

Belle

- based on 772 M $B\bar{B}$ (full data sample),
- four τ decay channels: $e\nu\nu$, $\mu\nu\nu$, $\pi\nu$, $\rho\nu$;
- improved tracking,
- improved tagging (NeuroBayes),
- K_L veto added,
- better understanding of the peaking background,
- signal extracted from 2D fit in $(E_{\mathrm{ECL}}, M^2_{\mathrm{miss}})$,
- $\mathcal{B} = (0.72^{+0.27}_{-0.25} \pm 0.11) \times 10^{-4}$.

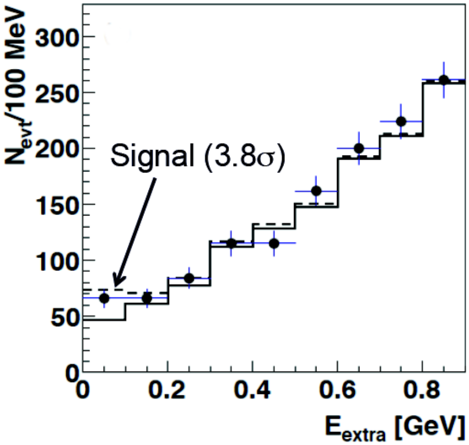


Belle PRL 110, 131801 (2013)

$B^+ \to \tau^+\nu$ by hadronic tag - *BABAR*

Belle

- based on 468 M $B\bar{B}$ (full data sample),
- four τ decay channels: $e\nu\nu$, $\mu\nu\nu$, $\pi\nu$, $\rho\nu$;
- improved tagging efficiency -larger set of hadronic tag modes
  - $\times 2$ in respect to previous tagging method
- $\mathcal{B} = (1.83^{+0.53}_{-0.49} \pm 0.24) \times 10^{-4}$.

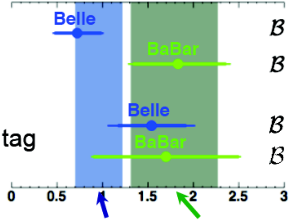


BABAR arXiv: 1207.0698

$B^+ \to \tau^+\nu$ measurements summary

Hadronic tag

Semileptonic tag



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

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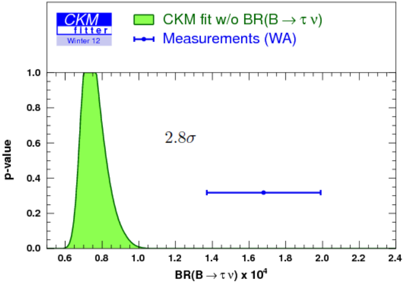
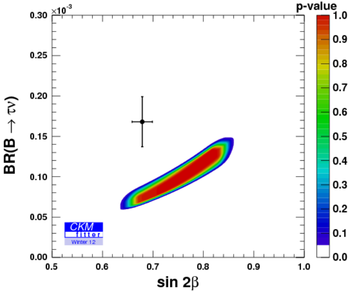
Belle combined: $\mathcal{B}$=(0.96±0.26)x10^{-4} BaBar combined: $\mathcal{B}$=(1.79±0.48)x10^{-4}

Naive world average $\mathcal{B} = (1.15 \pm 0.23) \times 10^{-4}$.





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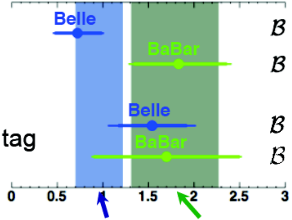

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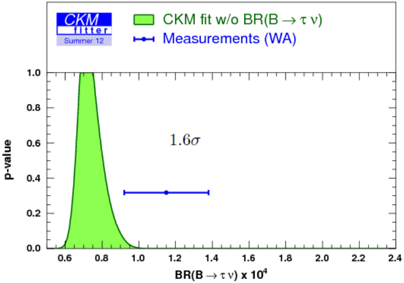
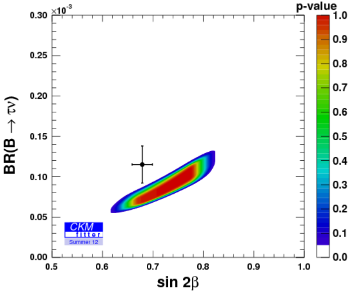




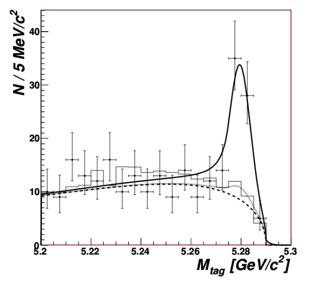
$B \to D^{(*)}\tau\nu$ measurements

First we reconstruct B_{sig} then the left over tracks and clusters in calorimeter are used to B_{tag} reconstructions.

Signal extraction based on tag side variables:

$M_{tag} = \sqrt{E_{beam}^2 - \mathbf{p}_{tag}^2}$

Belle $B^- \to \bar{D}^{*0}\tau^-\nu$:



- Of course signal should be also visible on signal side variables (MM^2, $D^{(*)}$, h and ℓ momentum)

In Principe less constraints on signal side:

- less model dependent constraints on signal side distributions or,
- kinematic distributions from fits in M_{tag} bins

A. Matyja *et al.*, [Belle Collaboration], Phys. Rev. Lett. **99**, 191807 (2007)

Inclusive vs Exclusive analysis

Exclusive

- lower B_{tag} efficiency,
- large number the $D^{(*)}$ decays channels,
- the τ decays limited to leptonic decays $\to \ell\nu\nu$,
- the signal extraction based on B_{sig} variables.

The latest *BABAR* analysis is called *inclusive* $\to$ higher tagging efficiency, $\to$ reconstruction starts from B_{sig}

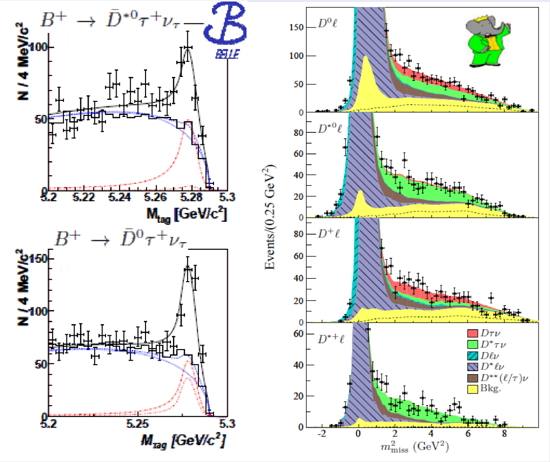
Inclusive

- higher B_{tag} efficiency,
- only the cleanest $D^{(*)}$ decays are used,
- the $\tau^+ to \to \ell^+\nu\nu$, $\pi^+\nu$ and $\rho\nu$ decay channels are included,
- the signal extraction based mostly on B_{tag} variables.

Unfortunately Belle has not yet shown data based on full data set.

All the Belle data below comes from published or presented earlier results

Signal extraction in the $B \to \bar{D}\tau^-\nu$ and $B \to \bar{D}^*\tau^-\nu$ channels.



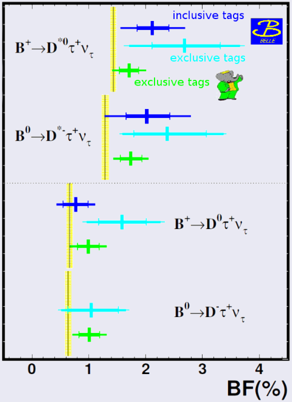
- large feed-across to $B \to \bar{D}\tau^+\nu$ channels from $B \to \bar{D}^*\tau^-\nu$,
- especially important for $B^+ \to \bar{D}^0\tau^+\nu$ sample.
- $B \to \bar{D}^*\tau^+\nu$ channels are clean

Existing studies were oriented to maximize sensitivities not S/N

Belle PRD 82 (2010)
BABAR PRL 109 (2012)

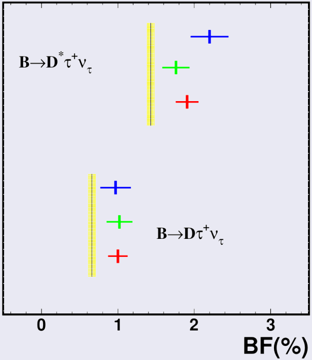
Branching fraction measurement

PRL 99 (2007) (535 × 10^6)
PRD 82 (2010) (657 × 10^6)
hep-ex/0910.4301 (657 × 10^6)
PRL 109 (2012) (471 × 10^6)



SM expectation

(S.Fajfer, J.Kamenik, I.Nisandzic, PRD **85**, 094025 (2012))

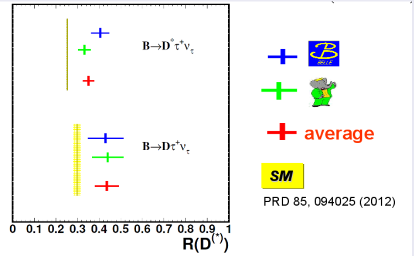


private average of Belle results

R measurement

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

$R(D) = 0.297 \pm 0.017,\ R(D^*) = 0.252 \pm 0.003$



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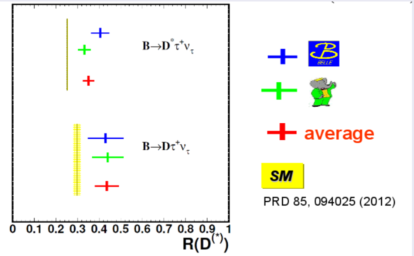
BABAR SM deviations

- $R(\overline{D}^*)$ 2.7σ
- $R(\overline{D})$ 2.0σ
- $R(\overline{D}^{(*)})$ 3.4σ



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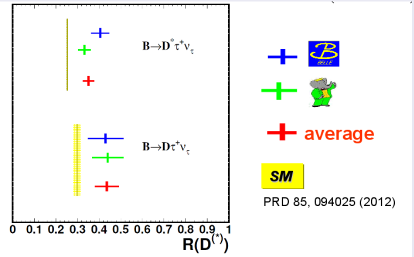
Belle average SM deviations

- $R(\overline{D}^*)$ 3.0σ
- $R(\overline{D})$ 1.4σ
- $R(\overline{D}^{(*)})$ 3.3σ



private average of Belle results

Belle and *BABAR* average deviation from **SM**

- $R(\overline{D}^*)$ 3.8σ
- $R(\overline{D})$ 2.4σ
- $R(\overline{D}^{(*)})$ 4.8σ

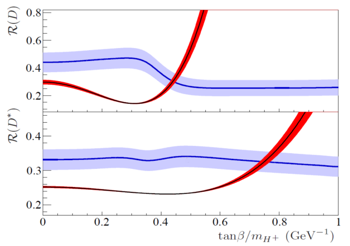
Observed deviations between observable and SM expectations for $R_{D^{(*)}}$ are not only due to improvement of experimental results but also reduction theoretical uncertainties.

LQCD expectations . A. Bailey, *et al.*, Phys. Rev. Lett. **109**, 071802, (2012), arXiv:1206.4992 [hep-ph].

$R(D) = 0.316 \pm 0.012 \pm 0.007$

Comparison with 2HDM-II

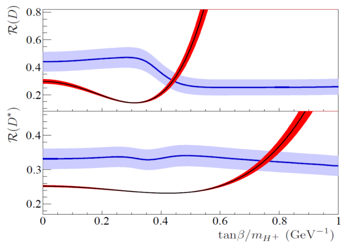
BABAR



experimental band $\longrightarrow$ acceptance variation with $\tan\beta/m_H^+$

Comparison with 2HDM-II

BABAR



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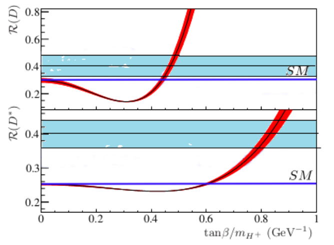

Acceptance variation with $\tan\beta/m_H^+$ was not included in that plot. Small for *exclusive* analysis.

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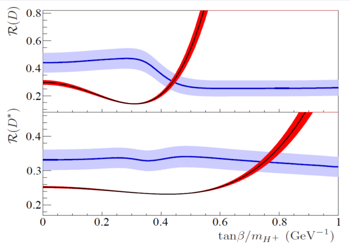

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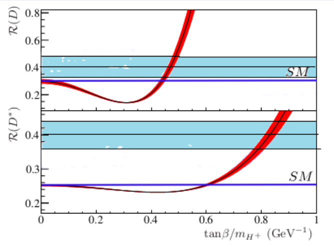

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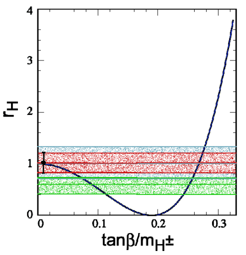
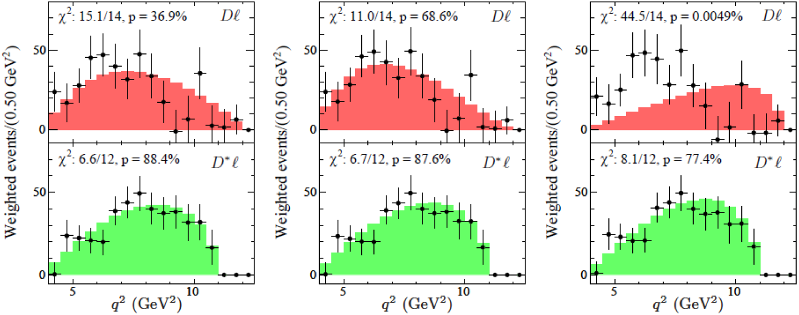


- R(r_H) in $B^+ \rightarrow \tau^+\nu$, $B \rightarrow \bar{D}\tau^+\nu$ and $B \rightarrow \bar{D}^*\tau^+\nu$ suggest different values of $tan\beta/m_{H\pm}$
  - $r_H \rightarrow \approx 0 - 0.1$ or ≈ 0.25 GeV^{-1}
  - $R_D \rightarrow \approx 0.4 - 0.5$ GeV^{-1}
  - $R_{D*} \rightarrow \approx 0.7 - 0.9$ GeV^{-1}
- The *BABAR* collaborations excludes 2HDM-II charged Higgs at 99.8% confidence level for any value of $tan\beta/m_{H\pm}$ and points on 2HDM-III.

Can we measure kinematic distributions?

q^2 distributions



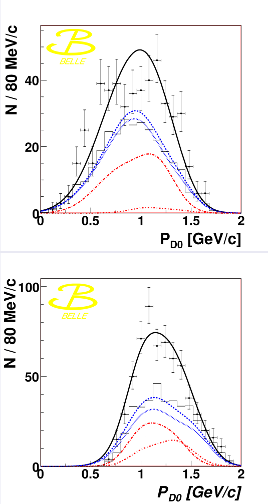
SM $\quad tan\beta/m_H^\pm = 0.30\text{GeV}^{-1} \quad tan\beta/m_H^\pm = 0.45\text{GeV}^{-1}$

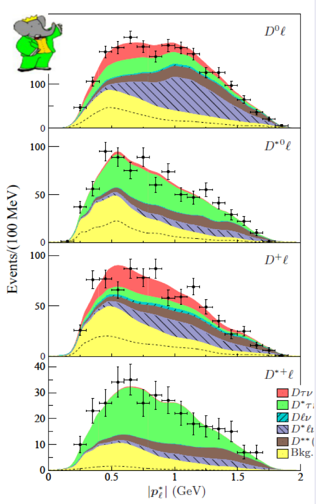
- large acceptance correction → see *BABAR* PRD paper:
  - contribution from $B \to \bar{D}^{**}(\tau^+/\ell^+)\nu$

	$B \to \bar{D}\tau^+\nu$	$B \to \bar{D}^*\tau^+\nu$
SM	83.1%	98.8%
$tan\beta/m_H^\pm = 0.30\text{GeV}^{-1}$	95.7%	98.9%
$tan\beta/m_H^\pm = 0.45\text{GeV}^{-1}$	0.4%	97.9%

J. P. Lees *et al.* [BABAR Collaboration], arXiv:1303.0571 [hep-ex], submitted to Phys. Rev. D.

Differential distributions for ℓ/h and $D^{(*)}$ momentum





- currently used for signal extraction

Belle PRD 82 (2010)
BABAR PRL 109 (2012)

Summary

- $B \to \tau\nu$ and $B \to D^{(*)}\tau\nu$ are sensitive tool for search NF,
- Recent $B \to \tau\nu$ results have weakened the tension with other measurements (CKM fits)$B \to \tau\nu$,
- The $R^{(*)}/BF$ measurement shows discrepancies from SM expectations (especially for $B \to D^*\tau\nu$ decays) $\to$ result improvement but also theory errors reduced.
- Current measurement are inconsistent with 2HDM-II models, complementary channels are pointing for different $tan\beta/m_{H^\pm}$ values(problem for MSSM ?)
- We can measure some kinematic distributions for $B \to D^{(*)}\tau\nu$ based on B- factory data sets, q^2, $|p_\ell|$, $|p_D^{(*)}|$.

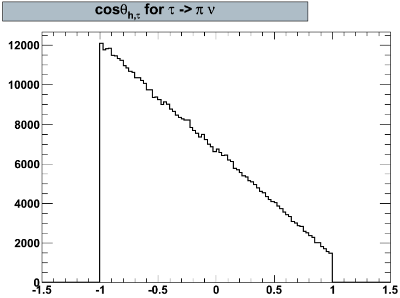
The new results from Belle, based on full statistic, is due soon.

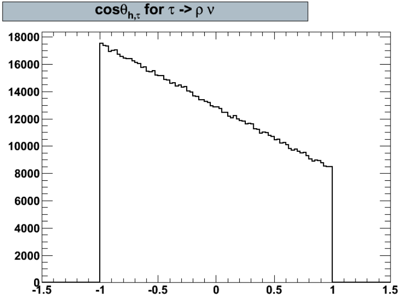
Belle II - run starts in2016

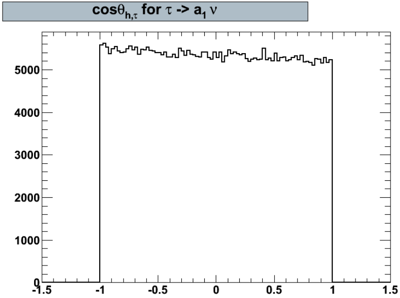
- It is important to improve the measurement of $B \to \tau\nu$ and $B \to D^{(*)}\tau\nu$ up to the level of few %.
- Improved measurement of kinematic distributions for $B \to D^{(*)}\tau\nu$ would allow to probe New Physics scenarios by looking to the correlations between different observables,

Backup

Tau polarization measurement



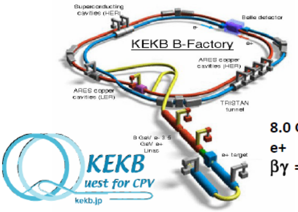




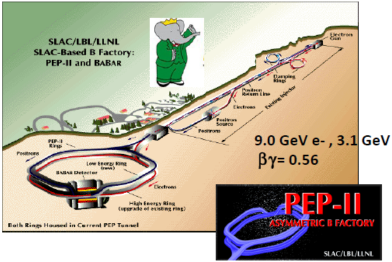
$B \to D^{(*)}\tau\nu$ results

Analysis	$\mathcal{B}$ [%]	R	significance
	$B^+ \to \bar{D}^{*0}\tau^+\nu_\tau$		
Belle incl.	$2.12^{+0.28}_{-0.27} \pm 0.29$	$0.372^{+0.049}_{-0.047} \pm 0.057$(*)	
Belle excl.	$2.68\ ^{+0.63}_{-0.57}\ ^{+0.34}_{-0.40} \pm 0.09$(*)	$0.47\ ^{+0.11}_{-0.10}\ ^{+0.06}_{-0.07}$	
Belle average	$2.24 \pm 0.29 \pm 0.15$	$0.393 \pm 0.051 \pm 0.027$	
BABAR	$1.71 \pm 0.17 \pm 0.13$	$0.322 \pm 0.032 \pm 0.022$	
WA	-	0.344 ± 0.036	
	$B^0 \to D^{*-}\tau^+\nu_\tau$		
Belle incl.	$2.02^{+0.40}_{-0.37} \pm 0.37$	$0.408^{+0.081}_{-0.075} \pm 0.077$(*)	
Belle- excl.	$2.38\ ^{+0.69}_{-0.59}\ ^{+0.30}_{-0.20} \pm 0.05$(*)	$0.48\ ^{+0.14}_{-0.12}\ ^{+0.06}_{-0.04}$	
Belle average	$2.24 \pm 0.29 \pm 0.15$	$0.393 \pm 0.051 \pm 0.027$	
BABAR	$1.74 \pm 0.19 \pm 0.12$	$0.355 \pm 0.039 \pm 0.021$	
WA	-	0.372 ± 0.039	
	$B^+ \to \bar{D}^0\tau^+\nu_\tau$		
Belle incl.	$0.77 \pm 0.22 \pm 0.12$	$0.341^{+0.097}_{-0.097} \pm 0.063$(*)	
Belle excl.	$1.58\ ^{+0.43}_{-0.41}\ ^{+0.25}_{-0.20} \pm 0.08$(*)	$0.70\ ^{+0.19}_{-0.18}\ ^{+0.11}_{-0.09}$	
Belle average	$0.95 \pm 0.21 \pm 0.08$	$0.420 \pm 0.091 \pm 0.034$	
BABAR	$0.99 \pm 0.19 \pm 0.13$	$0.429 \pm 0.082 \pm 0.052$	
WA	-	0.425 ± 0.069	
	$B^0 \to D^-\tau^+\nu_\tau$		
Belle excl.	$1.04\ ^{+0.48}_{-0.41}\ ^{+0.13}_{-0.11} \pm 0.06$	$0.48\ ^{+0.22}_{-0.19}\ ^{+0.06}_{-0.05}$(*)	
BABAR	$1.01 \pm 0.18 \pm 0.12$(*)	$0.469 \pm 0.084 \pm 0.053$	
WA	-	0.471 ± 0.090	

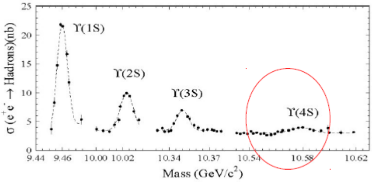
B factorie: Belle i *BABAR*

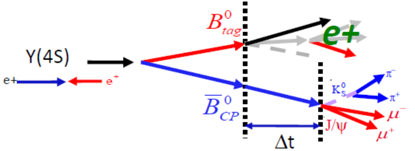


8.0 GeV e- , 3.5 GeV e+
βγ = 0.42

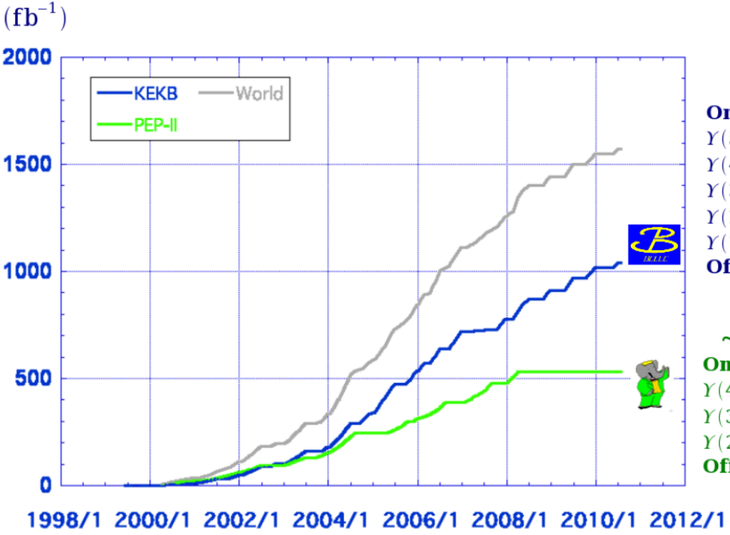


9.0 GeV e- , 3.1 GeV e+
βγ= 0.56





Accumulate Luminosity



> 1 ab^{-1}
On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1}
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 24 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

~ 550 fb^{-1}
On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

Charged Higgs search

The extended Higgs sector models contains charged $H^{\pm}$ bosons.

In the simplest extension of the SM, New Physics is coming from new scalar fields $\rightarrow$ 2HDM

The so called 2HDM of type II - One of the Higgs doublets is coupled with upper quarks, second to lower quarks. Same structure is the base of MSSM.

$tan\beta \equiv \frac{v_2}{v_1}$
v_1, v_2 - vacuum expectation

Belle II exclusion region from $B^+ \rightarrow \tau^+\nu$ decays.