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

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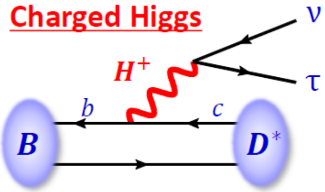
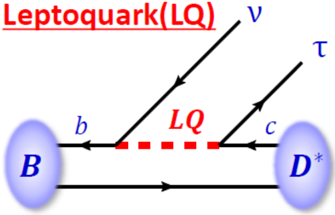
Outline

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

Physics motivations

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





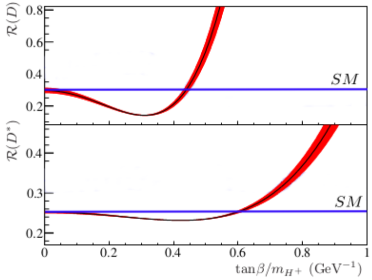
$B \to \overline{D}^{(*)}\tau^+\nu$

- 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



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

$$\mathrm{r}_H^{B\to\bar{D}^{(*)}\tau\nu} = R/R_{SM} = 1 + 1.5Re(C_{NP}^{\tau}) + 1.1|C_{NP}^{\tau}|^2$$

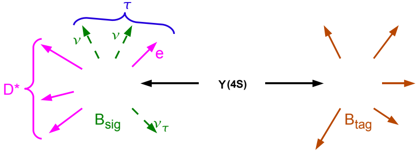
$$C_{NP}^{\tau} = -\frac{m_b m_\tau}{m_{H^\pm}^2}\frac{tan^2\beta}{1+\varepsilon_0 tan\beta}$$

The $B \to \bar{D}\tau\nu$ 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)

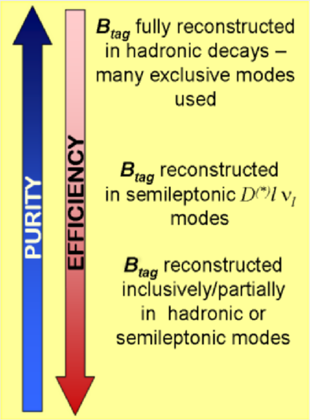
Experimentally challenging

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



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

Different approaches for B_{tag} reconstructions

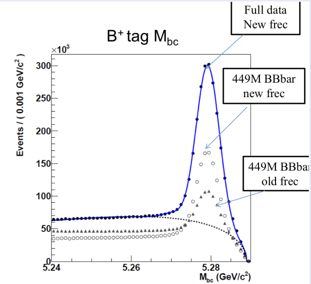


$\rightarrow B_{tag}$ momentum resolution

B_{tag} reconstruction

Hadronic decay tags:

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

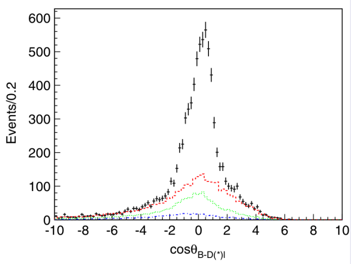


$$M_{bc} = \sqrt{E_{beam}^2 - \mathbf{p}^2}$$

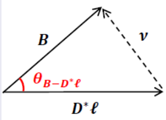
$$\Delta E = E - E_{beam}$$

Semileptonic decay tags:

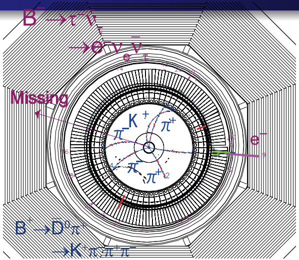
$B_{tag} \to D^{(*)}\ell\nu_\ell$



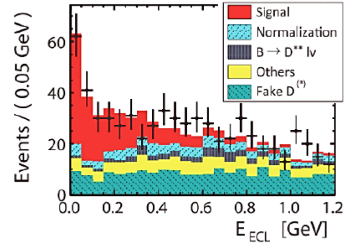
$$cos\theta_{B,D^{(*)}\ell} = \frac{2E_{beam}^{cms}E_{D^{(*)}\ell}^{cms} - m_B^2 - M_{D^{(*)}\ell}^2}{2P_B^{cms}.P_{D^{(*)}\ell}^{cms}}$$



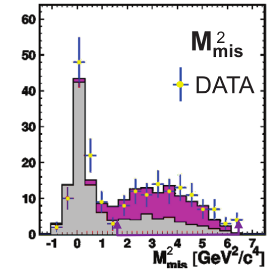
B_{sig} reconstruction



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



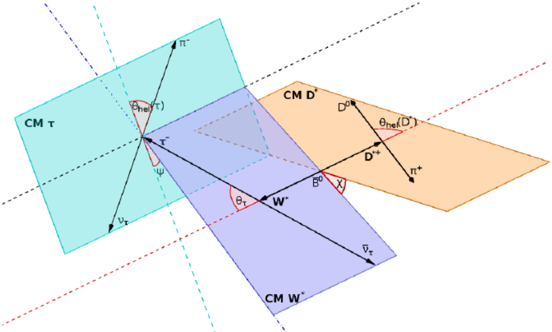
$MM2$ - missing mass square

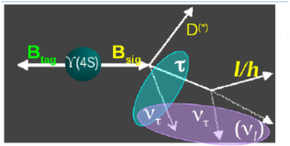


Y. Sato *et al.* [Belle Collaboration], arXiv:1607.07923 [hep-ex], 2016.

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

$B \to D^* \tau \nu$ angular variables





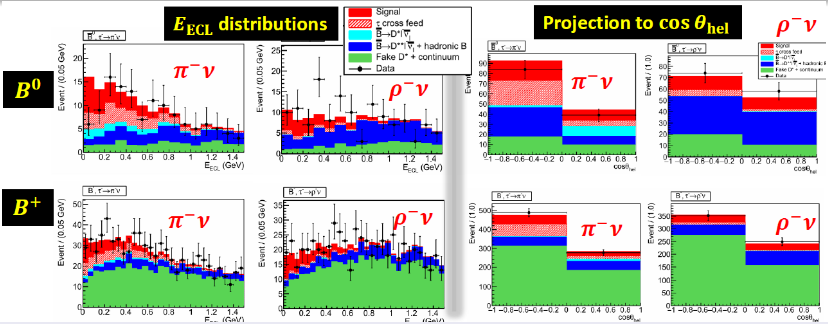
$MW^2 \equiv q^2 = (E_b - E_{D^{(*)}})^2 - (-p_{tag} - p_{D^{(*)}})^2$

$MM^2 = (E_b - E_{D^{(*)}} - E_{l/h})^2 - (-p_{tag} - p_{D^{(*)}} - p_{l/h})^2$

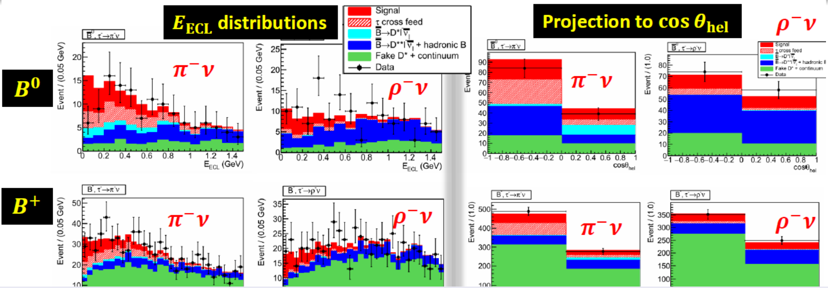
$\cos\theta_{hel}(D^*)$: MW^2 and p_{D^0}, $p_{\pi_{slow}}$
$\cos\theta_{hel}(\tau)$: MW^2, MM^2 and p_h (only for hadronic τ decays)

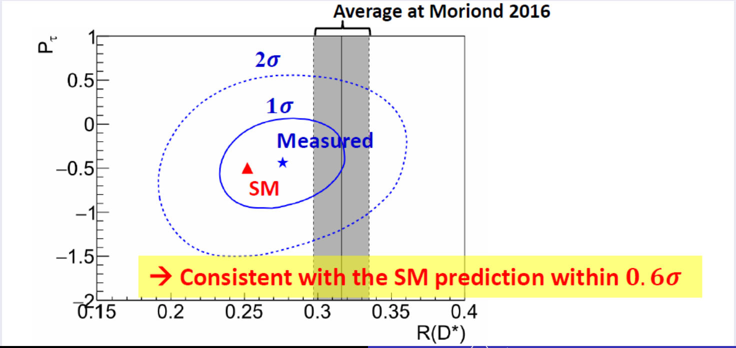
- τ polarization measurement from $\cos\theta_{hel}(\tau)$
  $\frac{d\Gamma}{d\cos\theta_{hel}(\tau)} \approx \frac{1}{2}(1 + \alpha P_\tau \cos\theta_{hel}(\tau))$
  $\alpha = 1$ for $\tau \to \pi\nu$
  $\alpha = 0.45$ for $\tau \to \rho\nu$
- SM: $P_\tau \approx -0.5$

- D^* polarization measurement from $\cos\theta_{hel}(D^*)$ distribution
  $\frac{d\Gamma}{d\cos\theta_{hel}(D^*)} \approx$
  $2F_L^{D^*}\cos^2\theta_{hel}(D^*) + (1 - F_L^{D^*})\sin^2\theta_{hel}(D^*)$
- SM: $F_L^{D^*} \approx 0.5$



- Determination of P_τ and $R(D^*)$ from hadronic tagging sample
- Simultaneous fit to $E_{\rm ECL}$ distributions.
- First P_τ measurement.
- Statistically limited → improvement with Belle II data



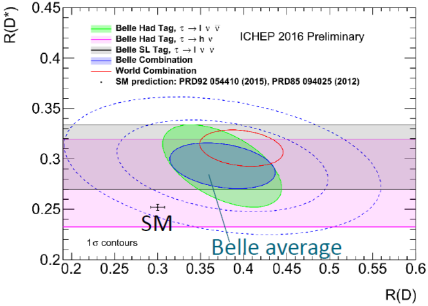


→ Consistent with the SM prediction within 0.6σ

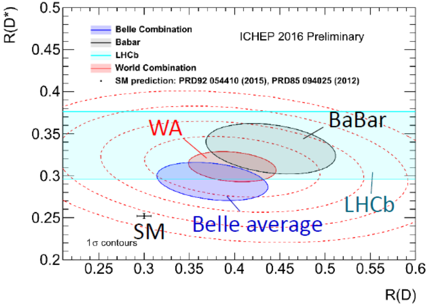
New results in 2016 from Belle

- First measurement of $R(D^*)$ using semileptonic tag,
  $R(D^*) = 0.302 \pm 0.030(stat) \pm 0.011(syst)$
- First measurement of τ polarization in $B \to D^*\tau nu$ decays,
  $R(D^*) = 0.276 \pm 0.034(stat)^{+0.029}_{-0.026}(syst)$, (from $\tau \to \pi\nu$, $\tau \to \rho\nu$ decays),
  $P_\tau = -0.44 \pm 0.47(stat)^{+0.020}_{-0.017}(syst)$

Belle combination



Comparison among experiments



- Precision of $R(D^*)$ is improved by combining Belle results.
- Belle $R(D^*)$ measurement is still larger then SM prediction but smaller the BaBar/LHCb measurements.

Future

D^* polarization

- all τ decays are useful
- not affected by crossfeeds between different τ decays

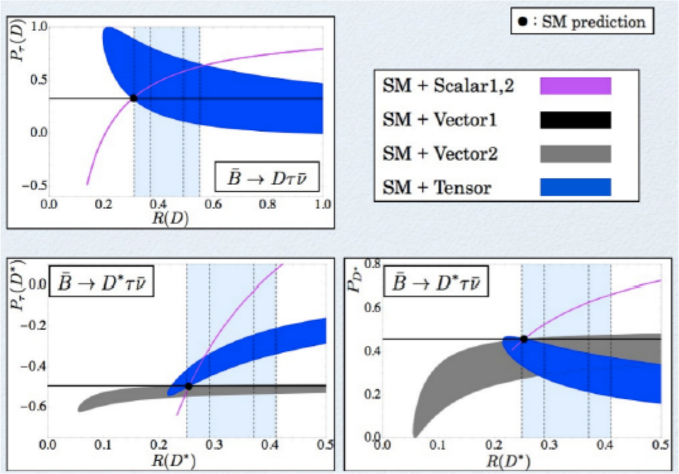
Belle II

- 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,
- $R(D)$ and $R(D^*)$ can be measured precisely (reduction of the total errors by factor of at least 5, understanding of D^{**} is crucial to reduce it by another factor of 2)
- q^2 distributions
- precise measurement of $\cos\theta_{D^*}$ for D^*
- $\cos\theta_{h,\tau}$ for τ
- measurements of other kinematic distributions possible.

Backup

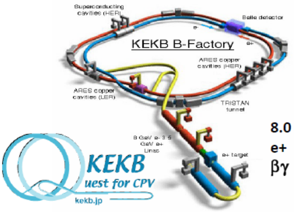
Motivation

Polarization measurements can provide more information on a structure on new interactions in model independent way.



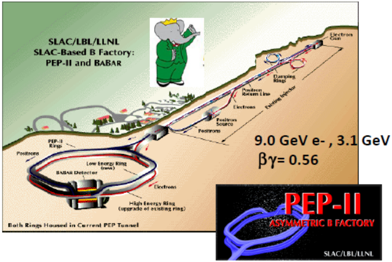
(R.Watanabe, talk at KEK-FF 2012)

B factories: Belle and *BABAR*

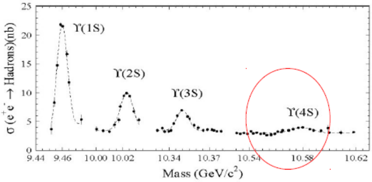


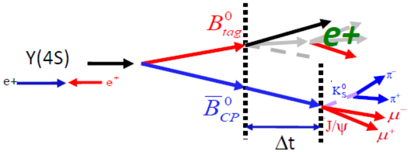
BELLE

8.0 GeV e- , 3.5 GeV e+
$\beta\gamma$ = 0.42

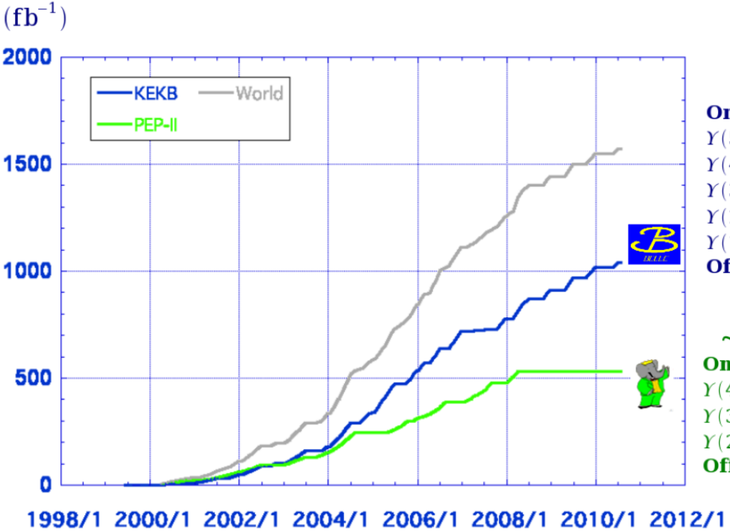


9.0 GeV e- , 3.1 GeV e+
$\beta\gamma$= 0.56





Accumulated 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:

$\sim$ 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:

$\sim$ 54 fb^{-1}