

Semitauonic B meson decays

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- Introduction
- Measurements at B factories
- Prospects at Belle2
- Summary

Why study $B \rightarrow X\tau\nu$

- Babar, Belle and LHCb measured:

$$R(D^{(*)}) = \frac{BR(B \rightarrow D^{(*)}\tau\nu)}{BR(B \rightarrow D^{(*)}\ell\nu)} \text{ with } \ell = \mu, e$$

- many systematic uncertainties cancel (theory and experiment)
- theoretical very "clean" as it is a tree level process
 - $\sigma(R(D^{*}))_{theory} \approx 2\%$
- good statistics $BR(B \rightarrow D^{*}\tau\nu) = 1.24\%$
- sensitive to new physics
- different channels to reconstruct for X and τ : $\tau \rightarrow \ell\nu_{\ell}\bar{\nu}_{\tau}$;
 $\tau \rightarrow \bar{\nu}_{\tau} + hadrons$

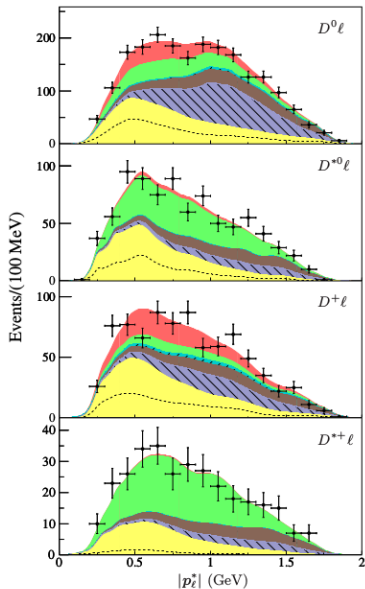
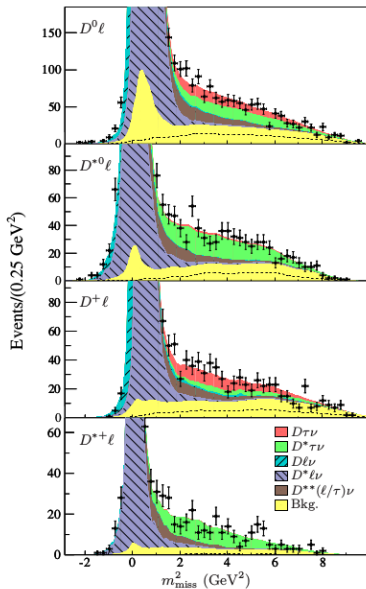
Experimentally challenging

- depending on channel 2-3 neutrinos in the event
- large backgrounds from $B \rightarrow D^{*,**}\ell\nu$ and secondaries
- signal is flat

Babar measurement

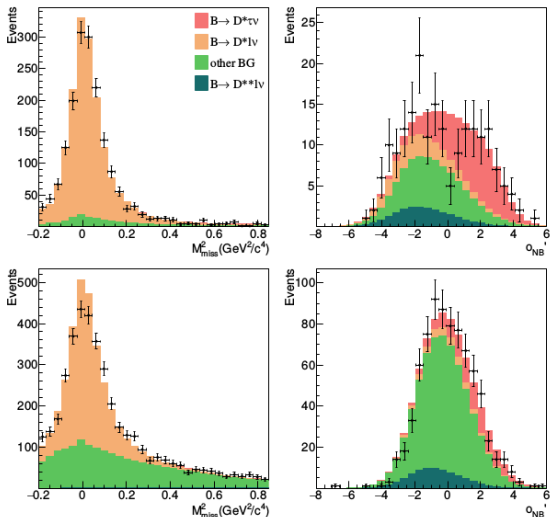
- fully reconstruct the tag side B meson in a hadronic decay mode (had. tag)
- require a lepton for the signal side μ or e
- require that $E_{extra} = \sum_{unmatched} E_{cal} < 0.5 GeV$
- define signal region with $q^2 > 4 GeV^2$
- no additional charged tracks in the event
- background rejection by 2 BDT:
 - reject continuum events
 - reject $B \rightarrow D^{**} \ell \nu$
- use control samples to constrain backgrounds from $B \rightarrow D^{**} \ell \nu$

- signal yields are extracted in a 2D maximum likelihood fit in $m_{miss}^2 = (p_{ee} - p_{tagB} - p_{D^{(*)}} - p_{\ell})^2$ and lepton momentum p_{ℓ}



- similar analysis from Belle (i.e. hadronic tag, leptonic tau decay)
- simultaneous fit in M_{miss}^2 and neural network output O_{NB}

Fit result for $B \rightarrow D^* \tau \nu$ channels ($D^{*\pm}$ top; D^{*0} bottom)



Belle measurement semileptonic tag

- use semileptonic $B \rightarrow D^{(*)}\ell\nu$ decays to tag the other B meson:
 - large statistics:
 $BR(B \rightarrow D^{(*)}\ell\nu) \approx 8\%$ (each, e^\pm and μ^\pm)
 - more difficult due to additional neutrino on tag side
- reconstruct events with two leptons (e, μ)
- use

$$\cos\theta_{B(D^{(*)}\ell)} = \frac{2E_{beam}E_{D^{(*)}\ell} - m_B^2 - M_{D^{(*)}\ell}^2}{2|\vec{p}_B||\vec{p}_{D^{(*)}\ell}|}$$
 to distinguish signal $B \rightarrow D^{(*)}\tau\nu$ and normalization $B \rightarrow D^{(*)}\ell\nu$
- select lower $\cos\theta_{B(D^{(*)}\ell)}$ as signal

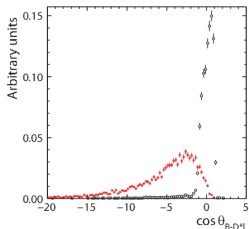
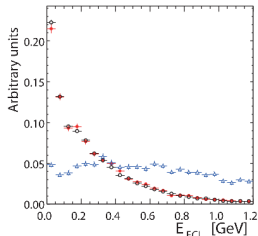
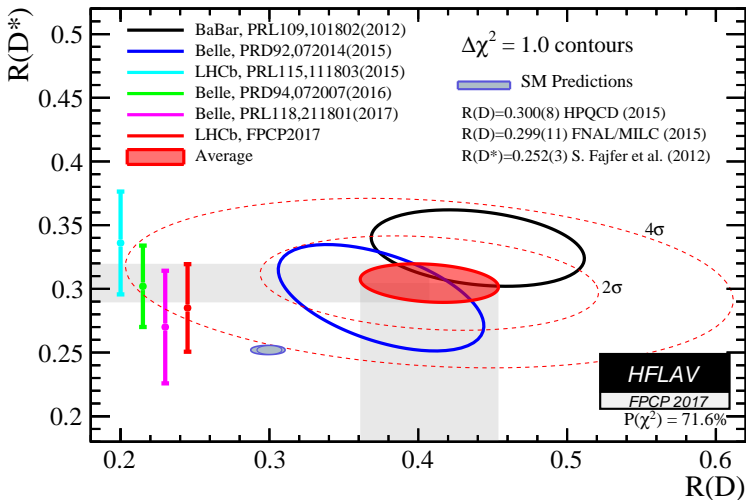


FIG. 1. The $\cos\theta_{B-D^{(*)}}$ distributions for $\bar{B}^0 \rightarrow D^{*+}\tau^-\bar{\nu}_\tau$ (solid red circles) and $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$ (open black circles) taken from MC simulation.



Current world of average for $D(D)$ vs. $R(D^*)$

- current world average is 3.9σ away from SM prediction



(dashed curves correspond to 2-3-4 σ contours)

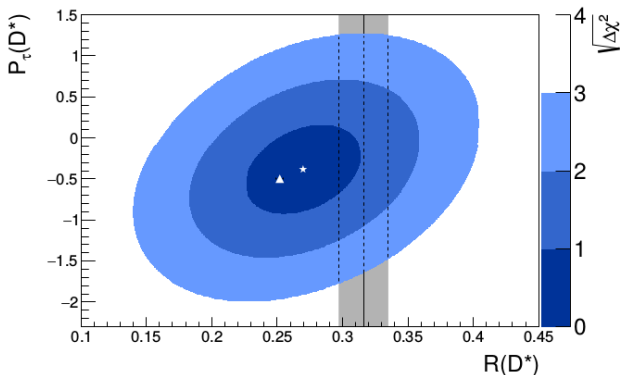
- discrepancy to SM consistent over different experiments and different channels
 - hadronic tag: fully reconstruct one B meson in a $B\bar{B}$ event
 - semileptonic tag: reconstruct a lepton (μ, e) on the tag side (not signal) for $B\bar{B}$ events
 - reconstruct the τ in leptonic channel $\tau \rightarrow \ell\nu_\ell\nu_\tau$
 - reconstruct the τ in hadronic channel e.g. $\tau \rightarrow \pi\nu_\tau$; $\tau \rightarrow \rho\nu_\tau$
- \Rightarrow different systematic effects:
- not easy to pick up systematic bias

Measurements used by HFLAV

Experim.	R(D*)	R(D)	corr. c.	Remarks
BaBar	$0.332 \pm 0.024 \pm 0.018$	$0.440 \pm 0.058 \pm 0.042$	-0.27	had. tag, lep. τ
BELLE	$0.293 \pm 0.038 \pm 0.015$	$0.375 \pm 0.064 \pm 0.026$	-0.49	had. tag, lep. τ
BELLE	$0.302 \pm 0.030 \pm 0.011$	-	-	semilep. tag, lep. τ
LHCb	$0.336 \pm 0.027 \pm 0.030$	-	-	hadron machine
BELLE	$0.270 \pm 0.035^{+0.028}_{-0.025}$	-	-	had. tag, had. τ
Average	$0.310 \pm 0.015 \pm 0.008$	$0.403 \pm 0.040 \pm 0.024$	-0.23	$\chi^2/\text{dof} = 3.17/5$ (CL = 0.67)

Measured polarization of the τ (arXiv:1612.00529)

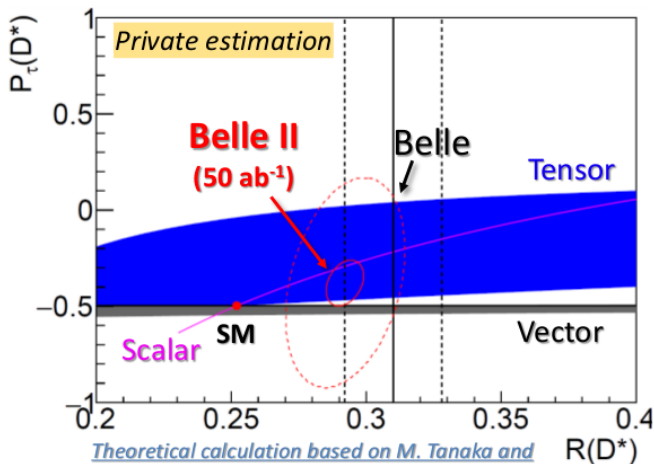
- investigate the polarization of the τ
- sensitive to new physics
- Belle first measured the polarization of the τ in $B \rightarrow D^* \tau \nu$; with had. tag and $\tau \rightarrow \pi \nu$; $\tau \rightarrow \rho \nu$
- suffers from low statistics \Rightarrow can be improved by Belle2



- presented by P. Urquijo at the Tau mini workshop in Nagoya, March 2017

$$R(D^*) = 0.270 \pm 0.035(\text{stat.}) \begin{matrix} +0.028 \\ -0.025 \end{matrix}(\text{syst.})$$

$$P_\tau(D^*) = -0.38 \pm 0.51(\text{stat.}) \begin{matrix} +0.21 \\ -0.16 \end{matrix}(\text{syst.})$$

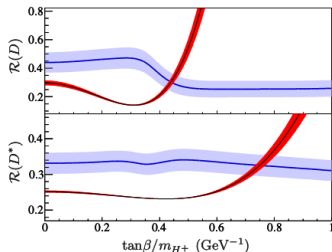


Constraint on NP models

- the measurement of $R(D^{(*)})$ can be used to constrain NP models
- e.g. charged Higgs (2HDM type II) input parameter $\tan\beta/m_{Higgs}$
- deduce from the measurement:
 - from $R(D^*)$:
 $\tan\beta/m_{Higgs} = 0.75 \pm 0.04$
 - from $R(D)$:
 $\tan\beta/m_{Higgs} = 0.44 \pm 0.02$
- excludes 2HDM type II with $P > 99.8\%$ for $m_{Higgs} > 15\text{GeV}$

Babar measurement (similar for Belle)

- efficiency corrected measurement of $R(D^{(*)})$ (blue)
- prediction of $R(D^{(*)})$ from 2HDM model as function of $\tan\beta/m_{Higgs}$



Constraints on new physics models

- distributions of $q^2 = (p_B - p_{D^{(*)}})^2$, p_{lep} , $p_{D^{(*)}}$ are sensitive to new physics contributions
- by measuring them one can constrain NP models

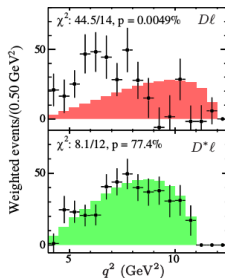
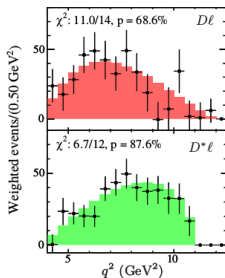
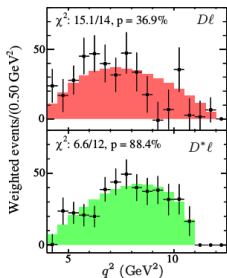
Example from Babar (but similar studies from Belle)

- background subtracted measured q^2 distribution compared to the 2HDM model for different values of $\tan \beta / m_{Higgs}$

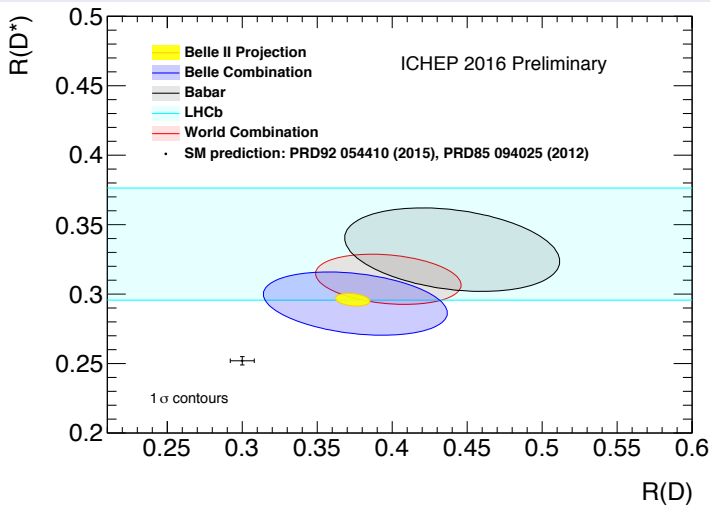
$\tan \beta / m_{Higgs} = 0.0$

$\tan \beta / m_{Higgs} = 0.3 \text{ GeV}^{-1}$

$\tan \beta / m_{Higgs} = 0.45 \text{ GeV}^{-1}$



Prospects at Belle2 for $R(D)$ and $R(D^*)$



at $50ab^{-1}$ expected rel. uncertainty on $R(D) \approx 3\%$ and on $R(D^*) \approx 2\%$

Prospects at Belle2 continued

- high statistics allows to look into other channels e.g. $R(\pi)$ $R(D^{**})$
- one of the biggest bkg contributions from $B \rightarrow D^{**} \ell \nu$
 - currently not well measured
 - new measurements at Belle2 can help to constrain those further
- difference between sum of measured BR for exclusive modes $\sum_i BR(B \rightarrow X_i \ell \nu)$ and the also measure inclusive BR: $BR(B \rightarrow X \ell \nu)$:
$$\Delta = BR(B \rightarrow X \ell \nu) - \sum BR(B \rightarrow X_i \ell \nu) \approx 0.7\%$$
- unknown decays could pose further background to $B \rightarrow D^{(*)} \tau \nu$ analyses
- \Rightarrow needs further measurements

Semitauconic analysis group

- subgroup of semi leptonic B decays analysis group
- goal to measure $R(X)$, dN/dq^2 , dN/dp_{lep} , dN/dp_D , $P(\tau)$
- channels:
 - $B \rightarrow D\tau\nu$
 - $B \rightarrow D^*\tau\nu$
 - $B \rightarrow \pi\tau\nu$; $B \rightarrow \rho\tau\nu \Rightarrow R(\pi)$; $R(\rho)$
 - inclusive $B \rightarrow X\tau\nu$ decays
 - $B \rightarrow D^{(*)}\pi\tau\nu$
 - $B \rightarrow D^{**}\tau\nu$
- around 20 collaborators expressed interest in contributing

Idea for doing the analyses

- do the analyses as group effort
- have a common skimmed dataset
- have a common analyses framework

summary

- semitauonic B decays good proving ground for testing the SM
- currently several measurement of $R(D^{(*)})$ available
- tension to the SM (need further measurements)
- several aspects where Belle2 can improve
- the next years will be exciting

BACKUP

■ BSemiTauonicDecay Model

- Implemented both in the Belle and the Belle II libraries
- Effects from NP currents can be included based on the model-independent theoretical study

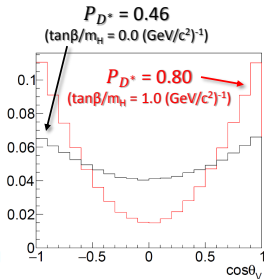
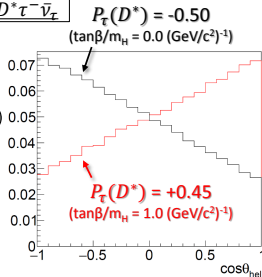
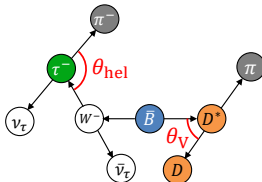
$$\mathcal{L}_{\text{eff}} = -2\sqrt{2}G_F V_{cb} \left[O_{V_1} + \sum_{i=V_1, V_2, S_1, S_2, T} C_i O_i \right]$$

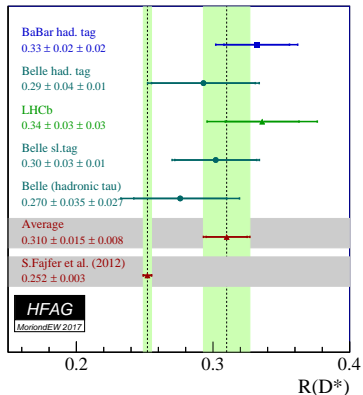
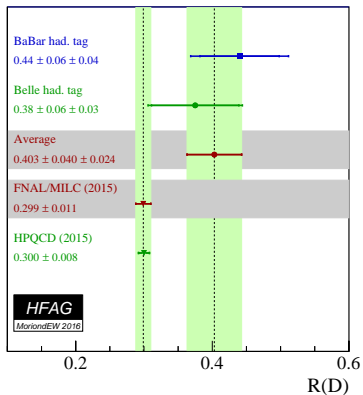
For type-II 2HDM:

$$C_{S_1} = -m_b m_\tau \left(\frac{\tan\beta}{m_{H^\pm}} \right)^2$$

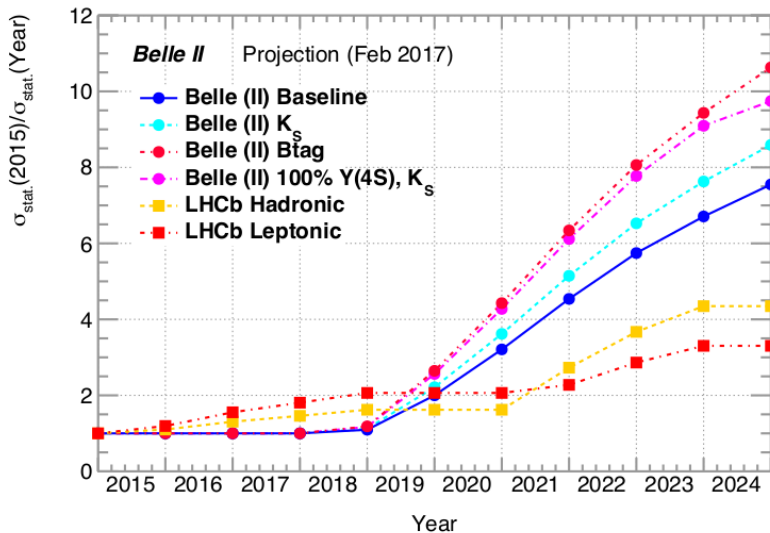
M. Tanaka and R. Watanabe, Phys. Rev. D 87, 034028 (2013)

Angular distributions for $\bar{B} \rightarrow D^* \tau^- \bar{\nu}_\tau$

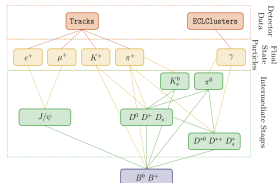
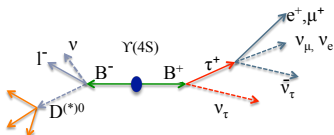




Phillip Urquijo, Tau mini workshop, Nagoya 2017



Belle II : Full event Interpretation



- Input variables used to train the multivariate classifiers:
 - PID, tracks momenta, impact parameters (**charged FS particles**);
 - cluster info, energy and direction (**photons**);
 - invariant mass, angle between photons, energy and direction (π^0);
 - released energy, invariant mass, daughter momenta and vertex quality ($D^{(*)}_{(s)}, J/\psi$);
 - the same as previous step plus vertex position, ΔE (**B**);
 - additionally, for each particle the **classifier output of the daughters** are also used as discriminating variables.

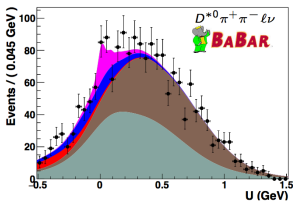
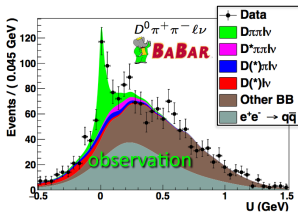


$B \rightarrow D^{(*)}\pi^+\pi^-\ell^-\bar{\nu}$ yields

BaBar PRL 116, 041801 (2016)

VISPA - Victoria Subatomic Physics

Channel	Yield	$\epsilon \times 10^4$	S	S_{tot}
$D^0\pi^+\pi^-\ell^-\bar{\nu}$	171 ± 30	1.18 ± 0.03	5.4	5.0
$D^+\pi^+\pi^-\ell^-\bar{\nu}$	56 ± 17	0.51 ± 0.02	3.5	3.0
$D^{*0}\pi^+\pi^-\ell^-\bar{\nu}$	74 ± 36	1.11 ± 0.02	1.8	1.6
$D^{*+}\pi^+\pi^-\ell^-\bar{\nu}$	65 ± 18	0.49 ± 0.02	3.3	3.0



S = statistical significance

S_{tot} = significance with systematics

