D^* polarisation measurements in $B \to D^* \tau \nu$ at Belle and Belle II. Model independent approach.

Mateusz Kaleta (Institute of Nuclear Physics PAS)

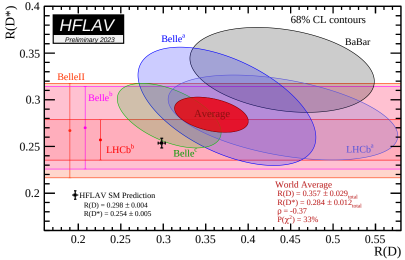
Jan 2024

Introduction

Motivation

- $B \to D^{(*)}\tau\nu$ decays are sensitive to new amplitudes at tree-level, heavy lepton in the final state
- Large number of observables: $R(D^{(*)})$, polarisations τ i D^*, q^2 distributions,
- Good theoretical tools; precise SM predictions, small hadronic uncertainties.

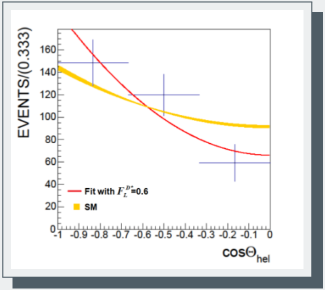
$$\mathrm{R}(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)}$$



Combined $R(D)$ and $R(D^*)$ in tension with SM prediction at 3σ level.

Current measurements: angular characteristics

D^* polarisation at Belle



- The signal yields obtained in the bins of $cos\theta_{hel}$ were re-weighted with the following scale factors (s_l) to correct for acceptance variations.
- Correction factors s_l extracted from MC **assuming Standard Model decay dynamics**

$cos\theta_{hel}$	s
$(-1, -0.67)$	0.98 ± 0.01
$(-0.67, -0.33)$	0.96 ± 0.01
$(-0.33, 0)$	1.08 ± 0.01

$B^0 \to D^{*-}\tau^+\nu_\tau$

$\tau^+ \to \ell^+\nu_\ell\bar{\nu}_\tau, \tau^+ \to \pi^+\bar{\nu}_\tau$

$F_L(D^*) = 0.60 \pm 0.08\ (stat) \pm 0.04\ (syst)$

Results consistent with SM prediction at $1.6\sigma - 1.8\sigma$

Karol Adamczyk. PhD thesis, [arXiv:1903.03102] (Belle Collaboration)

Current measurements: angular characteristics

D^* polarisation at LHCb (2023)

$B^0 \to D^{*-}\tau^+\nu_\tau$

$\tau^+ \to \pi^+\pi^-\pi^+(\pi^0)\nu_\tau$

$F_L(D^*) = 0.43 \pm 0.06\,(stat) \pm 0.03\,(syst)$

Compatible with SM predictions and with Belle results.

[arXiv:2311.05224v1] (LHCb Collaboration)

τ polarisation at Belle

$B \to \bar{D}^*\tau^+\nu_\tau$

$\tau^- \to \pi^-\nu_\tau,\ \rho^-\nu_\tau$

$P_\tau = -0.38 \pm 0.51\,(stat) \pm 0.20\,(syst)$

Consistent with SM prediction at 0.6σ

[PRL118 211801 (2017), PRD97 012004 (2018)] (Belle Collaboration)

Both measurements performed assuming Standard Model decay dynamics.

Goal of this analysis

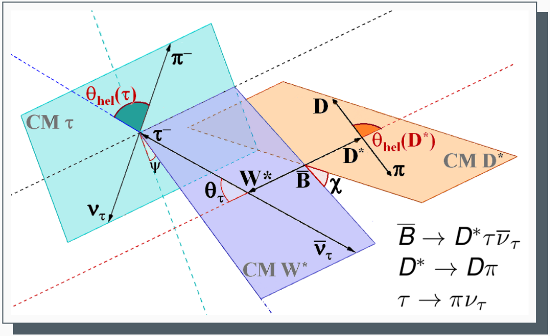
Main goal

- Enhancing experimental constraints on $B \to \bar{D}^* \tau \nu_\tau$ by precise measurements of angular observables.
- Focusing on $F_L(D^*)$.

Specific goals

- **Model-independent corrections for acceptance effects**
- Increase stastistics w.r.t. previous Belle analysis:
  - combined analysis of Belle and Belle II data
  - adding charged B channel: $B^+ \to D^* \tau \nu$
  - including more D decay channels in the analysis
- Perform measurements in several q^2 bins

Kinematic variables



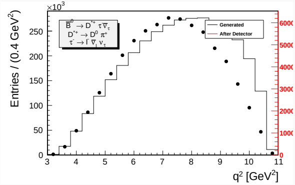
- q^2 - effective mass squared of the $\tau\nu$ system
- $\theta_{hel}(D^*)$ - angle between D and B in D^* rest frame

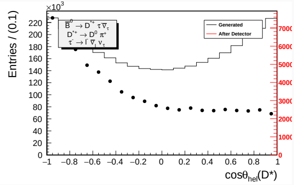
$$\frac{1}{\Gamma}\frac{d\Gamma}{dcos\theta_{hel}(D^*)} = \frac{3}{4}\left[2F_L(D^*)\,cos^2\theta_{hel}(D^*) + \left(1 - F_L(D^*)\right)sin^2\theta_{hel}(D^*)\right]$$

q^2 and $cos\theta_{hel}(D^*)$ can be reconstructed at B-factories with hadronic decays of B_{tag}

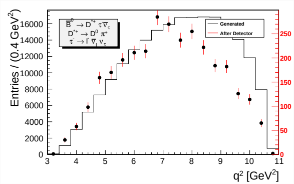
Acceptance effects

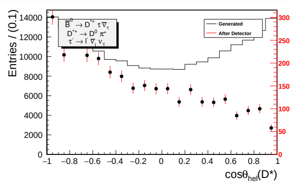
Belle





Belle II





Generated (black) vs. reconstructed* (red) q^2 and $cos\theta_{hel}(D^*)$ distributions for Belle (top) and Belle II (bottom).

*True kinematics is used for reconstructed events.

Decay channel: $\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$

$D^{*+} \to D^0\pi^+$

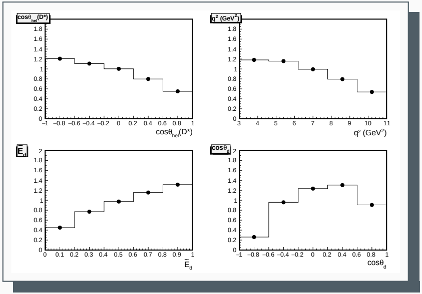
$\tau^- \to \ell\bar{\nu}_\ell\nu_\tau$

Signal decays generated assuming Standard Model decay dynamics.

Efficiency map

1. Pick four variables that characterize the decay and can be reconstructed experimentally:

- $cos\theta_{hel}(D^*)$ - cosine helicity angle D^*
- q^2 - four-momentum transfer squared
- $\tilde{E}_d$ - normalised τ daughter energy
- $\cos\theta_d$ - τ daughter polar angle



1D projections of 4D efficiency maps. Each variable was divided in 5 equidistant bins. Plot generated for Belle geometry, using Standard Model decay dynamics.

2. Create a 4D efficiency map by dividing reconstructed histograms by generated ones.

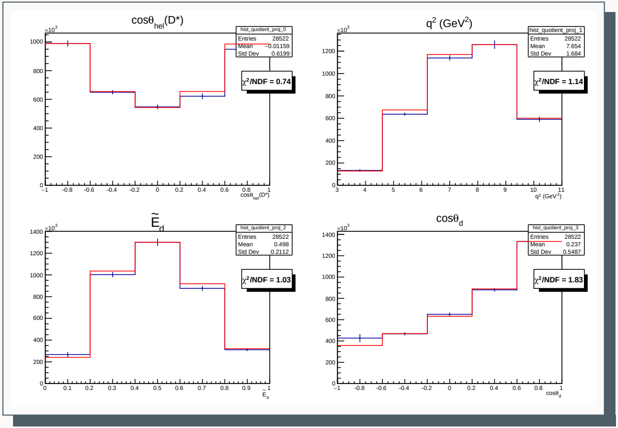
$$w_{ijkl} = \frac{N^{rec}_{ijkl}}{N^{gen}_{ijkl}} \frac{N^{gen}_{total}}{N^{rec}_{total}}$$

N_{ijkl} - number of events per bin

N_{tot} - total number of events

Reweighting

3. Reweight reconstructed distributions using w_{ijkl} to recover generated observables.



Generated (red) and reconstructed + reweghted distributions (blue). Plots made on independent sample generated with non-SM decay dynamics.

Summary

- Semitauonic B-meson decays currently on spotlight
- Improving experimental results for angular analyses can be useful for interpretation of current anomalies
- Studies on signal MC show the D^* polarisation measurement is challenging due to large acceptance effects
- We plan to apply model-independent acceptance corrections not considered previously