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

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November 14, 2017
Introduction

- Lots of information beyond branching fractions
  - $B \to D^{(*)}\ell\nu$ matrix element fully described by 2 (4) kinematic variables
  - Tau polarisation
- For muonic $\mathcal{R}(D^*)$ analysis, we fit $q^2$, muon energy, missing mass squared
  - These partially describe matrix element $\to$ we already have some information
- At present we assume SM kinematic distributions for $\mathcal{R}(D^*)$
- What additional information should we try to fit?
- What physics should we try to measure?
- Disclaimer: talk is almost entirely opinions, hopes and speculation
1. Introduction

Reconstruction ($\tau \rightarrow \mu \nu \nu$)

- Take $\langle \gamma \beta_z \rangle_B = \langle \gamma \beta_z \rangle_{D^*\mu}$
- Have approximation for rest frame with $\sim 15 - 20\%$ precision
- Can use this to calculate angles
Angular distributions

- What kind of resolution do we have on these angles?
Angular resolutions for $B \to D^* \mu \nu$

- Before taus, first look at angular resolution for $B \to D^* \mu \nu$ simulated events
Angular resolutions for $B \to D^*\tau\nu$

- Angular resolution for $B \to D^*\mu\nu$, $B \to D^*\tau\nu$ ($\tau \to \mu\nu\nu$)
- Tau decay results in loss of information
  - $\theta_\ell$ and $\chi$ degraded
  - $\theta_D$ about the same $\to D^{*+}(\Lambda_c)$ polarisation related observables maybe a good first target
- These resolutions aren’t horrific $\to$ we can make a measurement (with unknown sensitivity)
- These resolutions aren’t insignificant $\to$ we need to account for them...
- Unfolding?
Unfolding isn’t fundamentally sound

- Unfolding doesn’t have good statistical properties
- See e.g. R. D. Cousins, S.J. May, Y. Sun “Should unfolded histograms be used to test hypotheses?”
  - Spoilers: probably not
  - Even before biases introduced by regularisation
  - Going in the other direction is a fundamentally well defined procedure
- Describing the full space will require $O(1000)$ bins $\rightarrow$ not practical to unfold
- Uncertainty from background shapes difficult to reproduce accurately as a simple “background subtraction”
  - Often just ignored, we really cannot do this
Forward folding

- Don’t deconvolute data to theory, convolute theory to data
  - Best convolution: MC simulation
- This is exactly what we are already doing!
  - Can build on what we already have...
- Problem: model dependence - need to choose functional form
  - We will explore all possibilities
What can we do?

- Unfolding this seems a nightmare (as does background subtraction) → we are unlikely to publish corrected $q^2$ / angular distributions for signal
- But we can fit the data
  - Templates we fit already include effects of resolution, acceptance ...
- How to fit the data?
1. Introduction

**Histogram expansion PDF**

- What we want to do: reweight MC, reproduce histogram PDF
  - Event-by-event $\rightarrow$ slow
- Weight for each event can be written as
  $\sum [\text{(Combination of fit coefficients)} \times \text{(Stuff invariant in fit)}]$
  - (or expand it until it can be..)
  - Loop through events once, for each term generate a histogram
  - Adding up histograms, scaled by fit coefficients, exactly equivalent to fully reweighted histogram
- Only need to sum up histograms $\rightarrow$ fast
  - Already using for muonic $R(D^{(*)})$
What to measure

• First need to see if the excess holds up!
• Afterwards:
  • Does measured value change allowing NP operators?
  • Can enhancement be accommodated by theory uncertainty?
  • Pure vector/axial/tensor/...?
  • Or a combination of operators?
  • Can we fit the full matrix element?
Scalar form factor

- Trying to measure (pseudo)scalar form factor directly from $B \rightarrow D^{(*)} \tau \nu$ doesn’t seem so implausible
  - If no new (pseudo)scalar physics, and form factor agrees with prediction → model independent SM exclusion
  - Uncertainty from QED corrections?
- Testing SM only hypothesis → constrain other form factors from $B \rightarrow D^{(*)} \mu \nu$
- Not yet sure when we become sensitive enough
1. Introduction

Tau polarisation?

- With $\tau \rightarrow \mu \nu \nu$:
  - Some sensitivity to polarisation, but probably can’t disentangle from angular distribution?

- With $\tau \rightarrow \pi \pi \pi \nu$:
  - Combined $\pi \pi \pi$ momentum has little sensitivity to polarisation
  - But some information in substructure $\rightarrow$ exploring this
  - Thesis of Laurent Duflot (LAL 93-09)

- Measurement of polarisation and angular information correlated
- Physics of polarisation and angular information correlated
- We should consider both together
2. Conclusion

Conclusion

- We should explore what we can measure from the $B \rightarrow D^{(*)} \tau \nu$ and $B \rightarrow D^{(*)} \mu \nu$ kinematic distributions
- Unfolding and background subtracting looks like a nightmare
- Forward folding looks viable
  - At the cost of having to choose parameterisation(s) to fit with
Angular resolutions for $B \rightarrow D^{*} \tau \nu \ (\tau \rightarrow \pi \pi \pi \nu)$

- Situation similar for $\tau \rightarrow \pi \pi \pi \nu$ mode
- Different reconstruction method:
  - Can reconstruct kinematics up to quadratic ambiguities using $B$ and $\tau$ mass constraints + both vertex positions
  - Average over ambiguities
- Less information lost in tau decay, so Theta L a bit better?