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

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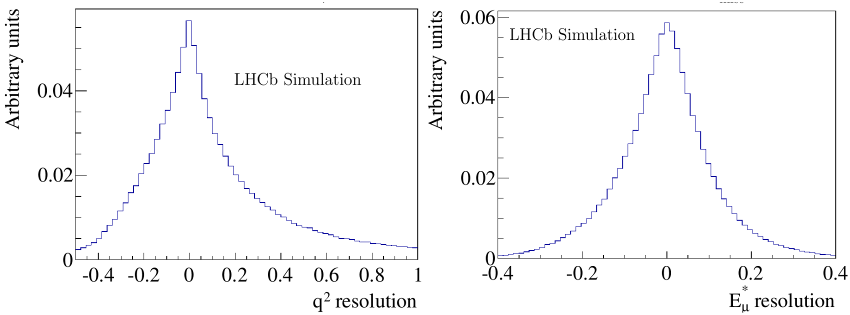
Introduction

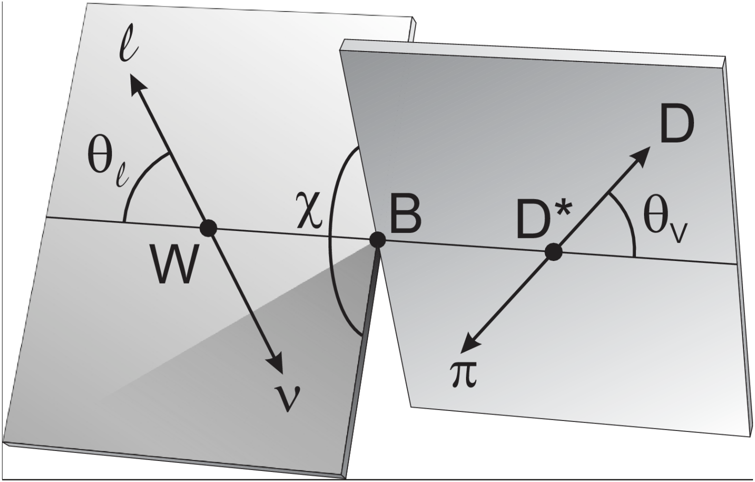
- Lots of information beyond branching fractions
  - $B \rightarrow D^{(*)}\ell\nu$ matrix element fully described by 2 (4) kinematic variables
  - Tau polarisation
- For muonic $\mathcal{R}(D^*)$ analysis, we fit q^2, muon energy, missing mass squared
  - These partially describe matrix element $\rightarrow$ 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

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



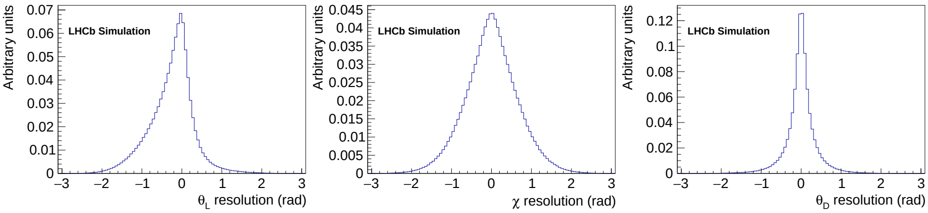
- Take $(\gamma\beta_z)_B = (\gamma\beta_z)_{D^*\mu}$
- Have approximation for rest frame with $\sim 15 - 20\%$ precision
- Can use this to calculate angles

Angular distributions



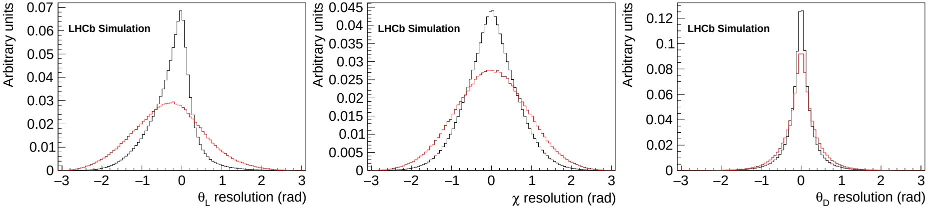
- What kind of resolution do we have on these angles?

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
  - θ_ℓ and χ degraded
  - θ_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) $\rightarrow$ 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?

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 $\mathcal{R}(D^{(*)})$

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

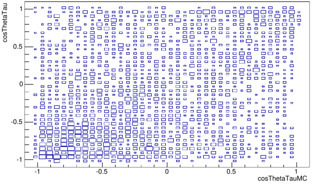
Tau polarisation?

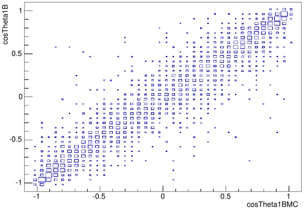
- With $\tau \to \mu\nu\nu$:
    - Some sensitivity to polarisation, but probably can't disentangle from angular distribution?
- With $\tau \to \pi\pi\pi\nu$:
    - Combined $\pi\pi\pi$ momentum has little sensitvity to polarisation
    - But some information in substructure $\to$ exploring this
    - 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

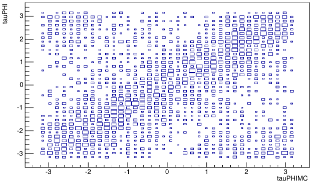
Conclusion

- We should explore what we can measure from the $B \to D^{(*)}\tau\nu$ and $B \to D^{(*)}\mu\nu$ 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 $B \to D^*\tau\nu$ ($\tau \to \pi\pi\pi\nu$)







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