$B \rightarrow D^{(*)} \tau \nu$

Greg Ciezarek, on behalf of the LHCb collaboration

Imperial College London

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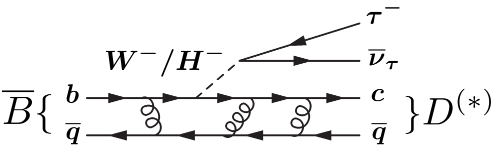
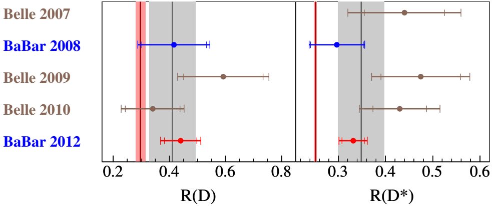
What we want to measure



- Ratio $\mathrm{R}(D^{(*)} = \mathcal{B}(B \to D^{(*)}\tau\nu)$ / $\mathcal{B}(B \to D^{(*)}\mu\nu)$ is sensitive to charged Higgs
  - Or non-MFV couplings favouring τ
- Theoretically clean:
  - $\sim 2\%$ uncertainty for D^* mode, $\sim 6\%$ for D
- Two τ decay modes considered:
  - $\tau \to \pi\pi\pi\nu$: sufficient statistics, but intimidating hadronic backgrounds
  - $\tau \to \mu\nu\nu$: measure $\mathrm{R}(D^*)$ directly, focus of this talk

Existing measurements

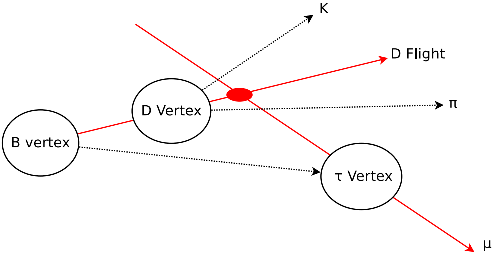


- Previous measurements from B factories in $\tau \to \ell\nu\nu$ channel
- Most recent measurement from BaBar claimed 3 σ excess over SM expectation
  - BaBar have used their final dataset, corresponding Belle measurement yet to come
- B factory measurements based on reconstructing missing mass using full event reconstruction
  - Not possible at LHCb

Experimental challenge

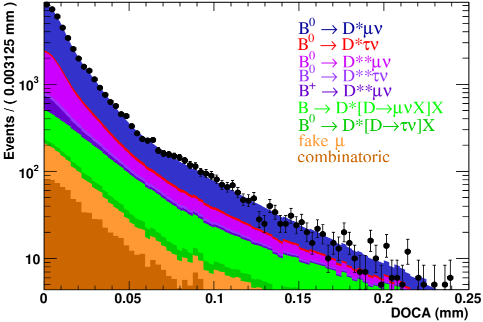
- Difficulty: 3 neutrinos for $(\tau \to \mu\nu\nu)\nu$
  - No narrow peak to fit (in any distribution)
- Main backgrounds: partially reconstructed B decays
  - $B \to D^{**}X$, $B \to D^{(*)}\mu X$, $B \to D^{(*)}D$ ...
- Also combinatorial background
- Need to find distributions which differentiate signal and background $\to$ fit
- Additional information used to reduce backgrounds:
  - τ flight (lifetime $= 87\mu m$)
  - Isolation

τ flight



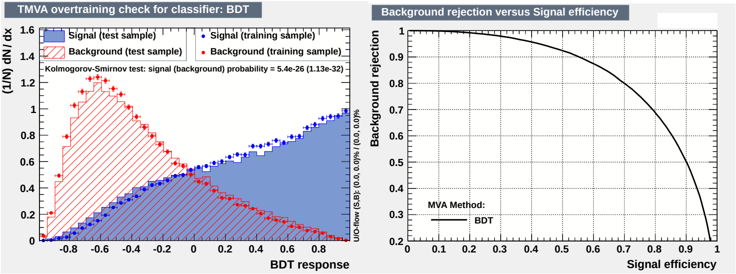
- Only have one track from τ $\rightarrow$ cannot reconstruct separate vertex
- Have [D μ], [D] vertices
  - Plus [D μ π_s], [μ π_s] [D π_s] in D^* case
- In cases where the τ flies further than the D ($\sim$ 25% of events), the [D μ] vertex may be downstream of the [D]
  - For μ modes, this can only happen due to resolution
- Use this information to separate $\tau^+ \rightarrow \mu^+\nu\nu$ from μ modes

DOCA



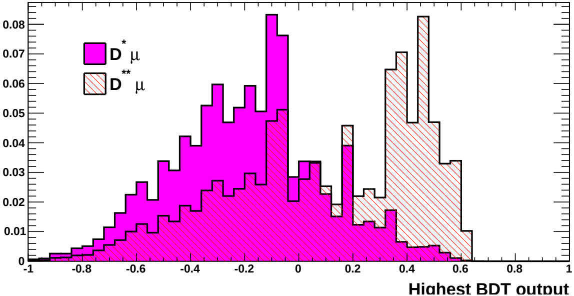
- One approach: Fit to distance of closest approach (DOCA) between muon and D
- Shows good separation between $B \to D^*\tau\nu$ and $B \to D^*\mu X$

Flight MVA



- Use MVA based on vertex positions, resolutions, track resolutions
  - Also works for $B \to D^0 \tau \nu$

Isolation MVA



- Strategy: use MVA to decide if each track is from the same B, or the rest of the event
  - Cut on most same-B-like track in event
  - Output based on properties of track, and $B + track$ combination
- Highest MVA output distribution for D^{**} and $B \to D^{*}\mu\nu$
- Inverting the cut gives a sample hugely enriched in D^{**} (anti Isolation) $\rightarrow$ use this to control shapes

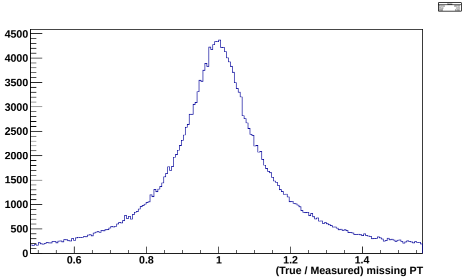
Overview of backgrounds

- Largest physics backgrounds: $B \to D^{**}\mu$, $B \to D^{(*)}D$ (with $D \to \mu X$)
- $B \to D^{**}\mu$:
  - Poorly measured, mass spectrum and decay modes unknown
  - Look in data to see which states need to be included
  - Yields cannot be constrained by $D^{*}\mu + \mathit{track}$ or external measurements
  - Independent component for each D^{**} state in fit
- $B \to D^{(*)}D$
  - $D \to \mu X$ well measured
  - Can use $D^{*}\mu + \mathit{track}$ to constrain yield
  - Modelled using MC cocktail of many, many decay modes
  - Treated as a single component in the fit

Overview of backgrounds

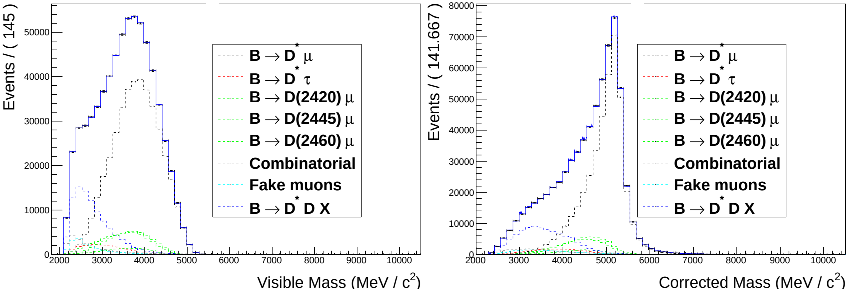
- Fake muon backgrounds taken from control sample in data
  - Can fix yield and shape
- Combinatorial background taken from same-sign data
  - Fake muon component subtracted from template
- $B \to D^{**}\tau$, $B \to D^{*}(D_s \to \tau\nu)X$ both small, not yet extensively studied

Fit strategy A



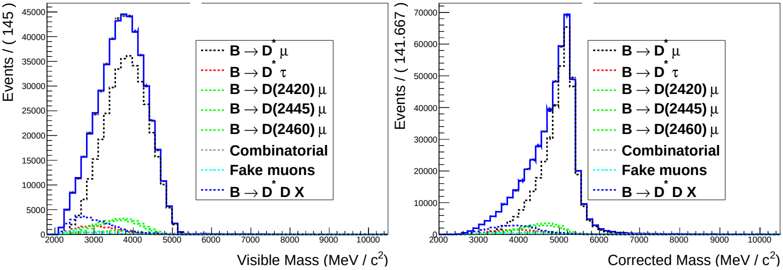
- Two fit strategies
  - Know B decay position, B momentum must point back to primary vertex $\rightarrow$ have measurement of missing transverse momentum
  - Can form "corrected mass" variable - minimum mass given a missing massless particle
    - Variable originates from SLD: hep-ex/0202031v1
  - 2D fit of visible and corrected mass

Fit strategy A



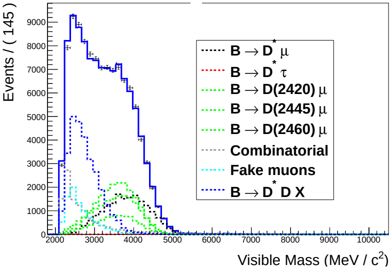
- Projections of 2D fit to **toy data** in visible mass (left), corrected mass (right)
- Event yields scaled to those expected in data
- No cuts on flight or isolation

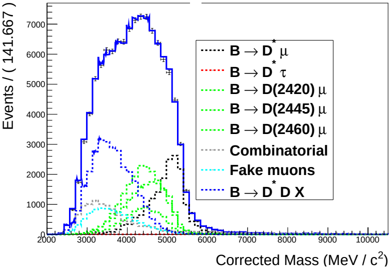
Toy fit (A)



- Toy study of fit in three bins of flight MVA, two bins of isolation MVA
  - Binning scheme not optimised
- Isolated, no flight:
  - $B \to D^* \tau \nu$ yield: $\sim$ 14,000 (3 fb^{-1})
- Control of background shapes key uncertainty
  - Especially D^{**}

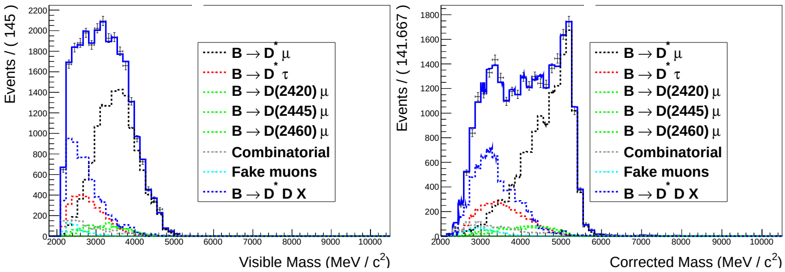
Toy fit (A)





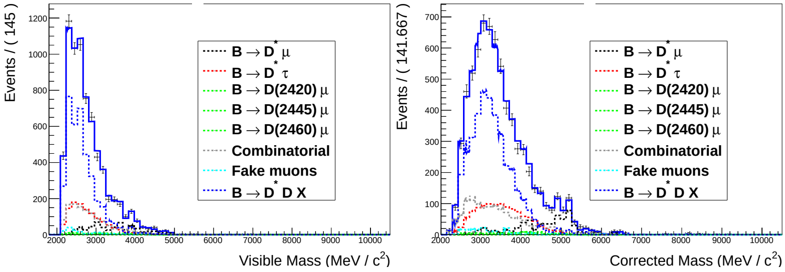
- Anti-isolated, low flight:
  - D^{**} backgrounds enhanced → use this sample to control shape
  - DD also enhanced → control shape and yield

Toy fit (A)



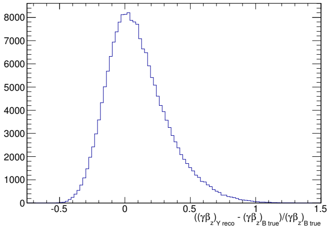
- Isolated, moderate flight:
  - $B \to D^* \tau \nu$ yield: $\sim$ 2500 (3 fb^{-1})
  - τ component enhanced relative to D^{**}, $B \to D^* \mu \nu$
  - Combinatorial background, *DD* larger

Toy fit (A)



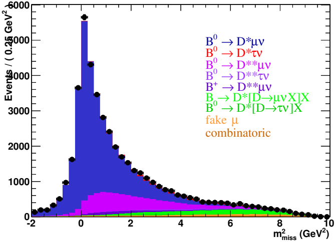
- Isolated, high flight:
  - $B \to D^* \tau \nu$ yield: $\sim$ 1000 (3 fb^{-1})
  - τ component dominates $\mu, D^{**}\mu$ modes
  - $B \to DD$ dominant background
- Combined: competitive statistical uncertainty on $B \to D^* \tau \nu$ yield

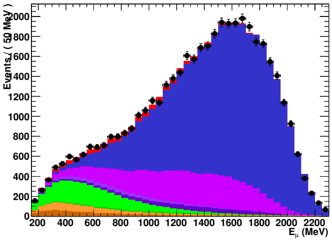
Fit strategy (B)



- Different starting point → use estimate of longitudinal momentum to access rest frame kinematics
  - B boost >> energy release in decay
  - Assume $\gamma\beta_{z,visible} = \gamma\beta_{z,total}$
  - ∼18% resolution on B momentum, long tail on high side
- Can then calculate rest frame quantities - $m^2_{missing}$, E_μ, q^2, ...

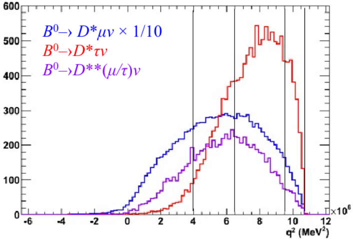
Fit strategy (B)





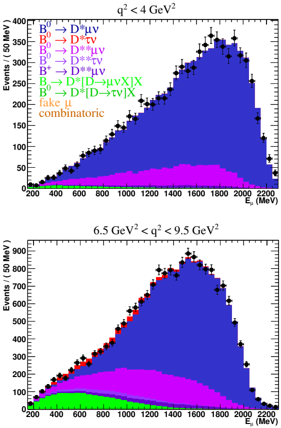
- Projections of 2D fit to **toy data** in missing mass squared (left), lepton energy (right)
- No cuts on flight or isolation

Toy fit (B)



- Using rest frame variables: fit in bins of q^2
- Four bins, vertical lines indicate boundaries

Toy fit (B)



- Background contributions change considerably between q^2 bins

Conclusion

- Measurement in progress in $\tau \to \mu\nu\nu$ channel
- Statistical uncertainty competitive with previous measurements
  - Control of systematics key
- Aim for detailed description of D^{**} backgrounds
  - Including form factor uncertainties - how large is reasonable?