Improved study of $\bar{B} \to D^{(*)}\tau\bar{\nu}$ with vertexing at Belle II

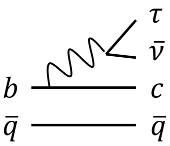
Sourav Dey

Tel Aviv Iniversity, Israel

On behalf of the Belle II Collaboration

July 14, 2018

Introduction

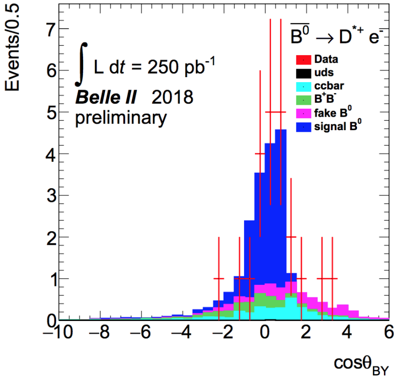


- Largest cross section for τ production in B decays
- Sensitive to new physics that couples more strongly to heavy fermions (e.g., charged Higgs)
- Important physics at LHCb and Belle II
- $R(D^{(*)}) \equiv \frac{Br(\bar{B}\to D^{(*)}\tau\bar{\nu})}{Br(\bar{B}\to D^{(*)}\ell\bar{\nu})}$:currently 3.8σ from SM prediction[1]
- An important background is $\bar{B} \to D^{**}\ell\bar{\nu}$
  - D^{**}(Excited charm state) $\to D^{(*)} + pions/eta$(when unobserved)
- In this talk, we will mostly focuse $\bar{B} \to D^{**}\ell\bar{\nu}$ background at Belle II using precise vertexing.

[1]:arXiv:1709.00129:Belle

BelleII Overview so far

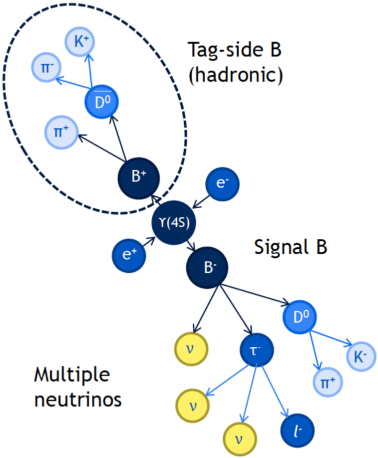
- Belle II is an e^+e- collider experiment operating primarily at the Υ(4S) resonance
- Produces $B\bar{B}$ and $\tau+\tau^-$ pairs, as well as $q\bar{q}$ background
- Phase 2 is currently in progress:
  - All Belle II subdetectors except vertex detector
  - D and B meson "rediscovery" in progress



$$cos\theta_{BY} = \frac{2E_B^* E_Y^* - M_B^2 - m_Y^2}{2p_b^* p_Y^*}$$

plot by Minakshi Nayak

Hadronic recoil-B reconstruction



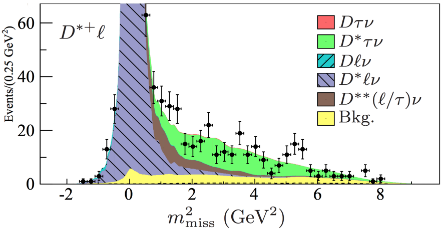
- Full Event reconstruction is helpful in missing energy studies and reducing backgrounds.
- These study uses Belle II's improved reconstruction algorithm
- This Hadronic full reconstruction is expected to be used for
  - semi-leptonic and semi-tauonic modes for $R(D^{(*)})$
  - $B \to \tau\nu$ decays

Missing Energy

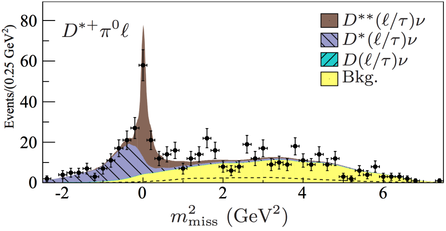
$$m^2_{miss} = (p_{ee} - p_{tag} - p_D - p_\ell)^2$$

* this image is taken from Sophie Hollitt's talk at ICHEP2018

m^2_{miss} and $\bar{B} \to D^{**}\ell\bar{\nu}$ background



1 mode in BABAR analysis



Simultaneous fit to $\bar{B} \to D^{**}\ell\bar{\nu} + \pi^0$ candidate

D^{**} systematic(%)	$R(D)$	$R(D^*)$
Relative efficiencies	5.0	2.0
$Br(D^{**} \to D^{(*)}\pi^0/\pi^\pm)$	0.7	0.5
$Br(D^{**} \to D^{(*)}\pi\pi)$	2.1	2.6
$Br(\bar{B} \to D^{**}\ell\bar{\nu})$	0.8	0.3
$Br(\bar{B} \to D^{**}\tau\bar{\nu})$	1.8	1.7

- $\sim 1.3 - 3.3\%$error in Belle [2] and LHCb [3] analyses with $\tau \to \ell\nu\bar{\nu}$

At Belle II ...

2% will already be a large error with 5 ab^{-1}

[1]arXiv:1205.5442, arXiv:1303.0571[2]arXiv:1507.03233 , arXiv:1607.07923 [3]arXiv:1506.08614

Known D^{**} states

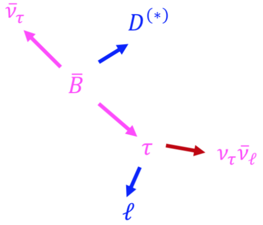
State	~Width (MeV)	J^P	Seen/allowed decays
$D_0^*(2400)$	270	0^+	$D\pi, D\eta$
$D_1(2420)$	27	1^+	$D^*\pi, D\pi\pi, D^*\pi\pi$
$D_1'(2430)$	380	1^+	$D^*\pi, D^*\eta, D^{(*)}\pi\pi$
$D_2^*(2460)$	50	2^+	$D^{(*)}\pi, D^{(*)}\pi\pi, D^{(*)}\eta$
$D(2550)$	130	0^-	$D^*\pi$
$D(2600)$	90	$?^?$	$D^{(*)}\pi$
$D^*(2640)$	< 15	$?^?$	$D^*\pi\pi$
$D(2750)$	65	$?^?$	$D^{(*)}\pi$

- Exclusive $\bar{B} \to D^{**}\ell\bar{\nu}$ decays observed only for the 4 lightest resonances
- Non-resonant $\bar{B} \to D^{**}\ell\bar{\nu}$ decays

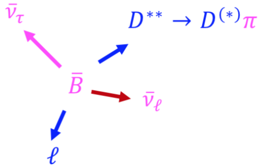
m^2_{miss} shape in the fit depends on our assumption. We need a model-independent handle on $\bar{B} \to D^{**}\ell\bar{\nu}$ background in $\bar{B} \to D^{(*)}\tau\bar{\nu}$

Distance between B vertex and lepton

Signal:

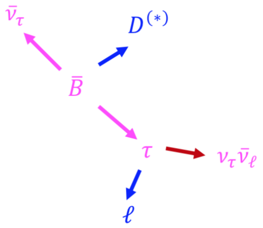


Background:

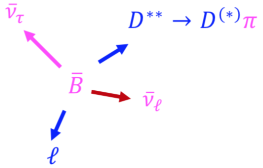


Distance between B vertex and lepton

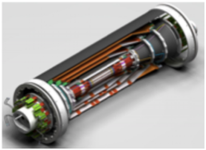
Signal:



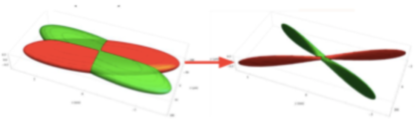
Background:



- Belle II spatial resolution is is twice as good as @ BABAR/Belle.
- Pixels @ $r = 14$mm:



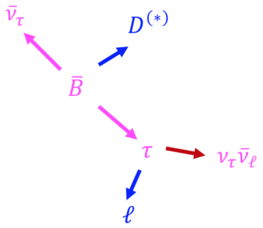
- Nanobeam collision scheme:



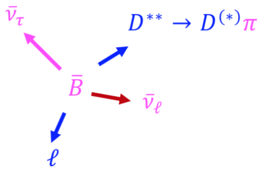
- Average τ flies only 45 μm, less than the Belle II spatial resolution,
- S-B separation weaker than for m^2_{miss} etc.
- But exploit model independence to check $\bar{B} \to D^{**}\ell\bar{\nu}$ yield in the analysis fit

Distance between B vertex and lepton

Signal:

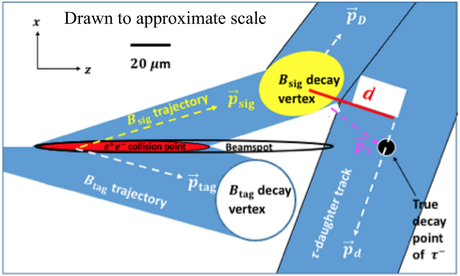


Background:



Exploit:

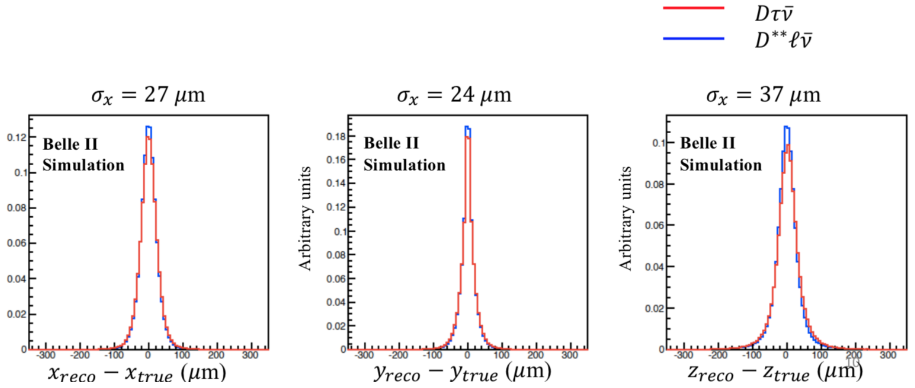
- Reconstruction of recoil B
- Very small beamspot
- Detector spatial resolution



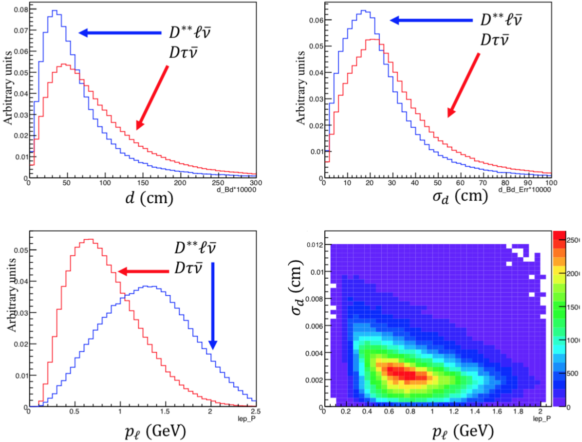
Study with Belle II GEANT4 simulation

- Not a complete analysis
- Studies only the separation between signal and $\bar{B} \to D^{**}\ell\bar{\nu}$
- Study only $B^- \to D^0\tau^-\bar{\nu}$(signal) $B^- \to D^{**0}\ell^-\bar{\nu}$(background)
- Assume correct tag-B and signal-B reconstruction
- Misreconstruction background is already handled with other analysis variables
- Results reflect a current snapshot of the reconstruction and analysis software

Signal-B position resolution



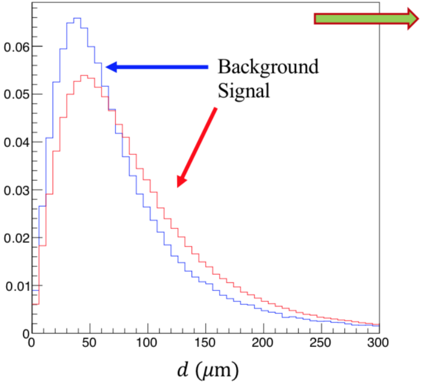
The distance d in $\tau \to \ell\nu\bar{\nu}$



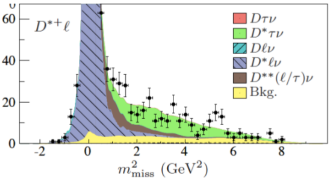
- Signal-Background separation is partly due to larger signal σ_d, which is due mostly to the softer lepton
- We focus on p_ℓ and see the correlation with σ_d

The distance d in $\tau \to \ell\nu\bar{\nu}$

After reweighting background events by lepton momentum:



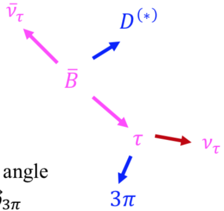
- The S-B separation is small
- But sufficient for verifying that the kinematic-variable fit gives the correct fraction of non-τ events.



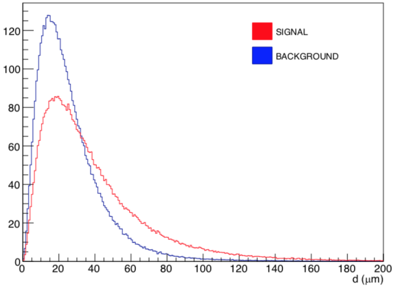
- Approximating signal and background yields from the BABAR analysis scaled to Belle II luminosity ($\times 100$), we find that a fit to the d distribution gives the prompt-lepton background yield with a $\sim 10\%$ error per mode $(D^0, D^+, D^{*0}, D^{*+})$

The distance d in $\tau \to 3\pi\nu$

Simulated background chosen just to test the capability to "see" the τ displacement:
$\bar{B} \to D3\pi2\nu$ with same kinematic distributions as signal

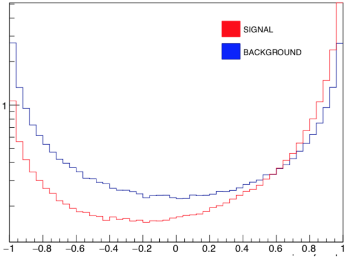


3-track vertex has much better resolution than single lepton:



d (μm)

Also measure the angle θ b/w $\vec{d}$ and $\vec{p}_{3\pi}$



$\cos\theta$

in background, τ is replaced by $\rho(3s)^-$

Summary

- $\bar{B} \to D^{(*)}\tau\bar{\nu}$ is an important part of the the physics programs of Belle II and LHCb
- In the $\tau \to \ell\nu\bar{\nu}$ mode, $\bar{B} \to D^{**}\ell\bar{\nu}$ background presents a systematic challenge
- Exploit Belle II's spatial resolution and small beamspot to obtain a new, model-independent handle on this background: distance , between the signal-B decay position and the lepton
- In the $\tau \to 3\pi\nu$ mode, 3 pions give improved precision on d and additional background suppression from the angle θ between d and the 3-pion momentum vector.
- Even better resolution expected for $\bar{B} \to \tau\bar{\nu}$. Currently under study.