Towards $B \to \pi\tau\nu$ at Belle II with semileptonic tagging

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Research Aims

- Belle II Experiment main aim to search for new physics through the study of rare decays
- Aim for this project: Establish a branching fraction for $\mathcal{B}(B \to \pi\tau\nu)$
- Possible further goal of measuring $R(\pi) = \frac{\mathcal{B}(B\to\pi\tau\nu)}{\mathcal{B}(B\to\pi\ell\nu)}$ for $\ell = e, \mu$
- SM Prediction: 0.641 ± 0.016 [1]
- Current upper bound of $\mathcal{B}(B^0 \to \pi^-\tau^+\nu) = 2.5 \times 10^4$ at 90% CL done with hadronic tagging at Belle [1]
- Perform such measurement with the use of semileptonic tagging

Motivation: Similar Measurements

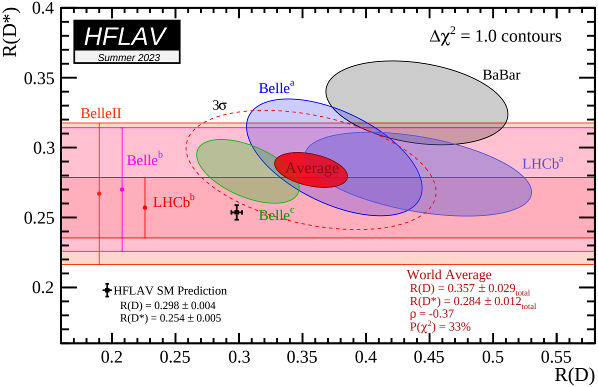


Figure: $R(D)$ and $R(D^*)$ Measurement [2]

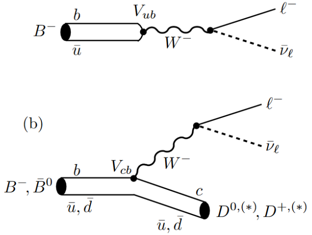
- Tension in both similar measurements for $R(D), R(D^*)$
- Belle II $R(D^*)$ measurement increases tension to 3.3σ
- Possibility of seeing similar phenomenon for light mesons requires more statistics

Theoretical Background

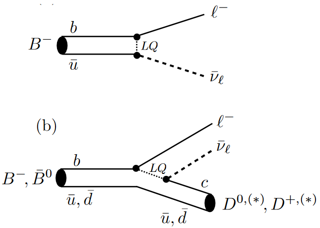
SM Differential Decay Rate $B \to \pi \ell \nu$:

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2 |V_{ub}|^2 |p_\pi| q^2}{96\pi^3 m_B^2} \left(1 - \frac{m_\ell^2}{q^2}\right)^2 \left[H_0^2(q^2) \left(1 + \frac{m_\ell^2}{q^2}\right) + \frac{3m_\ell^2}{2q^2} H_t^2(q^2) \right]$$

- Helicity amplitudes are functions of the form factors $f^{+/0}(q^2)$ parametrised in q^2: in terms of the 4-momentum transfer to the lepton
- Extensions to SM will change this term by modifying the helicity amplitudes

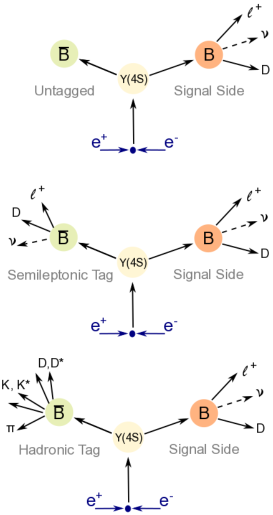


(a) Feynman Diagram under SM



(b) Possible leptoquark contributions

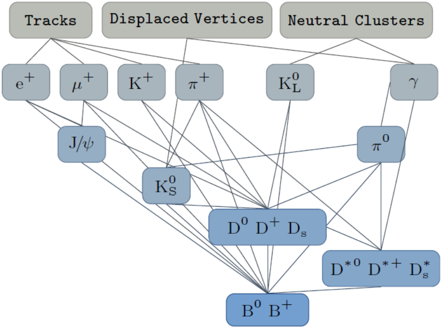
Tagging Analysis



- Selecting $\Upsilon(4S)$ candidates with our signal B meson and a tag B meson which decays in a pre-defined way
- Higher degree of tag knowledge improves the kinematic information of our signal B meson and reduces background
- Semileptonic tagging is employed as it provides a middle ground between untagged and hadronic tagging analyses

Full Event Interpretation

- Machine learning algorithm which reconstructs tag B mesons with a hierarchical approach
- Reconstructed tags have an output variable of signalProbability between 0 and 1 to indicate how background-like or how signal-like the B_{tag} is respectively
- Tagging efficiency of semileptonic tag $\varepsilon \approx \mathcal{O}(1\%)$
- FEI requires calibration to understand tagging performance



Semileptonic FEI Calibration via exclusive $B^0 \to D^{*-}\ell^+\nu$

Aim: Explore the use of $B_{sig}\cos\theta_{BY}$ to extract $B^0 \to D^{*-}\ell^+\nu$ to compare with expectation and use to extract calibration factor

- Retrieve calibration factor from calculation of branching fraction of $D^*\ell\nu$

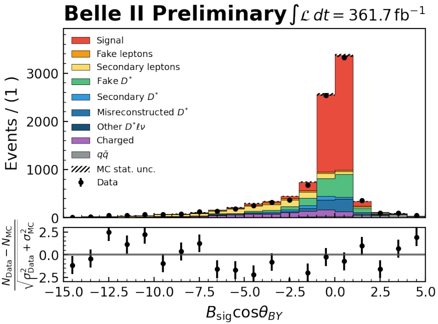
$$\mathcal{B}_{PDG}(B^0 \to D^{*-}\ell^+\nu) = \frac{N_{sig}^{data}(1+f_{+0})}{4\cdot\varepsilon\cdot CF_{SLFEI}\cdot\mathcal{B}_{PDG}(D^{*+}\to D^0\pi^+)\cdot\mathcal{B}_{PDG}(D^0\to D^0 \text{ Modes})}$$

- Fitting to $B_{sig}\cos\theta_{BY}$ for each B_{tag} tagmode
  $D\ell\nu,\ D^*\ell\nu,\ D\pi\ell\nu,\ D^*\pi\ell\nu$

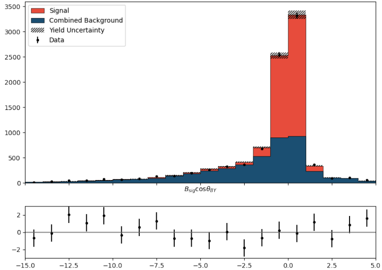
$$\cos\theta_{BY} = \frac{2E_{B,CMS}E_{Y,CMS} - m_B^2 - m_Y^2}{2|\vec{p}_B||\vec{p}_Y|}$$

- Signal Yield determined by 2 template fit of signal component and combined background of MC to data

$B_{sig} \cos\theta_{BY}$ Distributions (All tag modes)

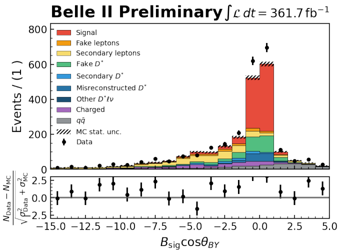


(a) Pre-fit with Signal $D^*\ell\nu$

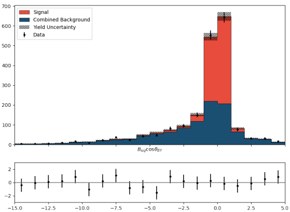


(b) Fit with Signal $D^*\ell\nu$

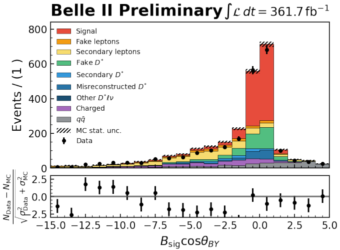
$B_{sig} \cos\theta_{BY}$ Distributions ($D\ell\nu$ tag modes)



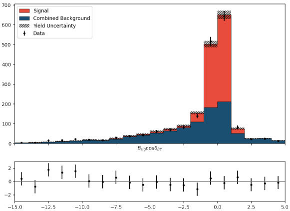
(a) Pre-fit with Tag $De\nu$



(b) Fit with Tag $De\nu$



(c) Pre-fit with Tag $D\mu\nu$



(d) Fit with Tag $D\mu\nu$

Preliminary Calibration factors at Skim Level

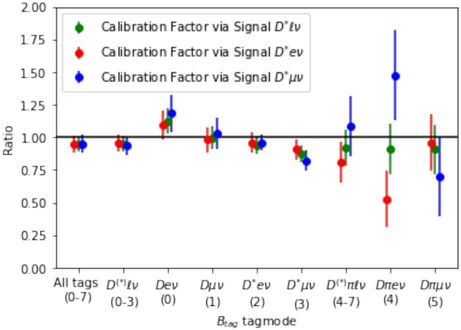


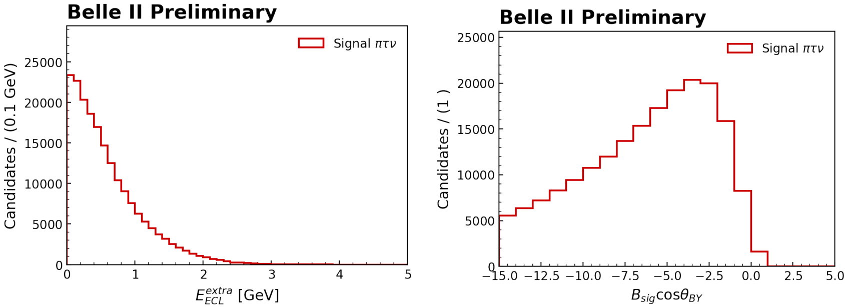
Figure: Tag decay mode ID listed in brackets

	Tagmode								
Signal mode	All tags (0-7)	$D^{(*)}\ell\nu$ (0-3)	$De\nu$ (0)	$D\mu\nu$ (1)	$D^*e\nu$ (2)	$D^*\mu\nu$ (3)	$D^{(*)}\pi\ell\nu$ (4-7)	$D\pi e\nu$ (4)	$D\pi\mu\nu$ (5)
$D^*\ell\nu$	0.95 ± 0.06	0.95 ± 0.06	1.12 ± 0.10	1.00 ± 0.08	0.94 ± 0.07	0.87 ± 0.06	0.92 ± 0.14	0.91 ± 0.19	0.91 ± 0.19
$D^*e\nu$	0.95 ± 0.06	0.96 ± 0.07	1.10 ± 0.11	0.98 ± 0.10	0.96 ± 0.08	0.91 ± 0.07	0.81 ± 0.16	0.53 ± 0.22	0.96 ± 0.22
$D^*\mu\nu$	0.95 ± 0.07	0.94 ± 0.07	1.18 ± 0.14	1.03 ± 0.12	0.96 ± 0.06	0.82 ± 0.08	1.09 ± 0.23	1.47 ± 0.35	0.70 ± 0.31

- Calibration factors for $D^*\pi\ell\nu$ (6-7) are not calculated due to limited statistics, but are included for the $D^{(*)}\pi\ell\nu$ calibration factor

Current Plan for $B \to \pi\tau\nu$

- Leptonic τ decays: $\tau \to (e/\mu)\nu\nu$
- Development of classifier to differentiate signal from background; shown variables have nice properties for discrimination



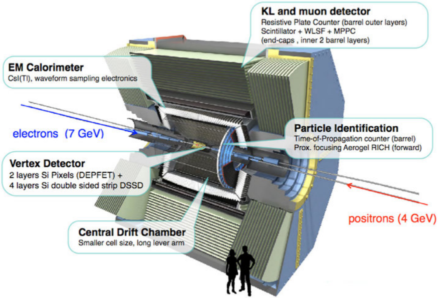
(a) E_{ECL}^{extra}: Extra energy deposited in the calorimeter not used in reconstruction of our $\Upsilon(4S)$

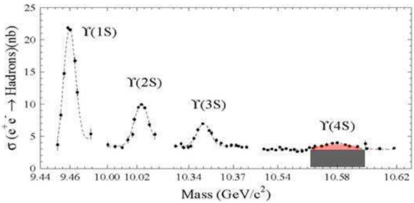
(b) $B_{sig}\cos\theta_{BY}$: cosine of angle between the momenta of the nominal B and its visible daughters

Backup Slides

Belle II Experiment

- SuperKEKB collides asymmetric beams of 7 GeV electrons and 4 GeV positrons
- Centre of mass frame corresponds to Upsilon $\Upsilon(4S)$ resonance at 10.58 GeV, which decays to $B\bar{B} > 96\%$ of the time
- Aim over experiment lifetime to achieve an integrated luminosity of 50ab^{-1} corresponding to 52.5 billion $B\bar{B}$ pairs





References

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