Study of $B^+ \to K^+\tau^+\tau^-$ decays using hadronic tagging

Debjit Ghosh
(University and INFN Trieste)

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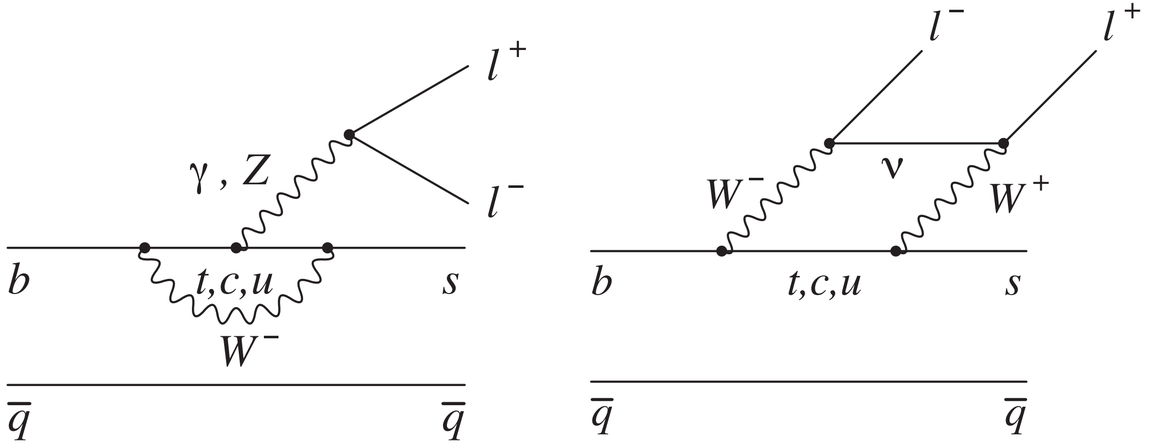
Motivation

- The flavour changing neutral current process, $b \to sll$, are forbidden at tree level in SM and only occurs via loop diagrams, $\mathcal{O}(10^{-7})$.



- Recent anomalies from LHCb measurements of $R_{K,K*}$ hint new physics models which predict enhancement of $\mathcal{B}(B^+ \to K^+\tau^+\tau^-)$ upto 3 orders.

- Importance of τ: 3^{rd} generation and higher mass strongly couples to new physics models.

- Current best constrained: *BABAR* collaboration put an upper limit with 424 fb^{-1} dataset, $\mathcal{B}(B^+ \to K^+\tau^+\tau^-) < 2.25 \times 10^{-3}$ at 90% C.L. [PhysRevLett.118.031802]

- There were attempts to search in Belle data using hadronic Full Reconstruction estimating a sensitivity of $\mathcal{B}(B^+ \to K^+\tau^+\tau^-) < 3.17 \times 10^{-3}$ at 90% C.L. [Belle Note- 1394]

- Started working on $B^+ \to K^+\tau^+\tau^-$ to do a combined Belle (Vidya *et al.*) + Belle II analysis

Analysis workflow

Reconstruction: process simulated data applying pre-selection of $B^+ \to K^+\tau^+\tau^-$

Background studies: continuum suppression and potential background sources

Optimise selection: identify selection that maximises signal to background ratio

Signal extraction or upper limit

Systematics: assess the relevant contribution to systematic uncertainties

Analysis procedure

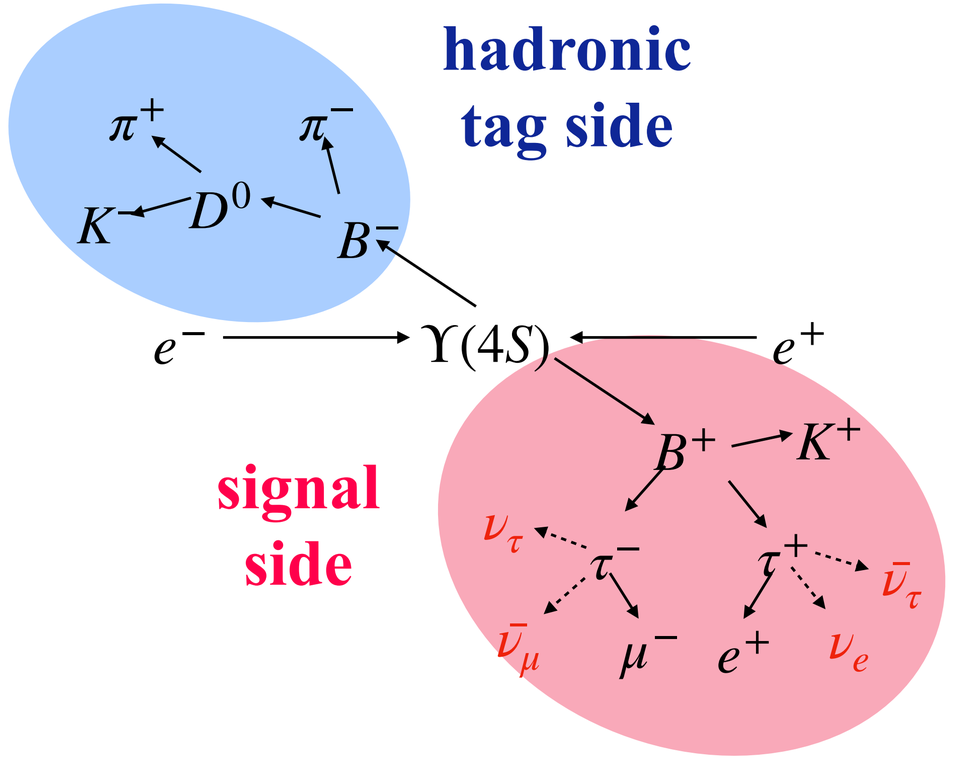
- With one prong τ decays ($\tau^- \to e^-\bar{\nu}_e\nu_\tau, \mu^-\bar{\nu}_\mu\nu_\tau, \pi^-\nu_\tau$), $B^+ \to K^+\tau^+\tau^-$ have $2-4$ neutrinos in the final state.

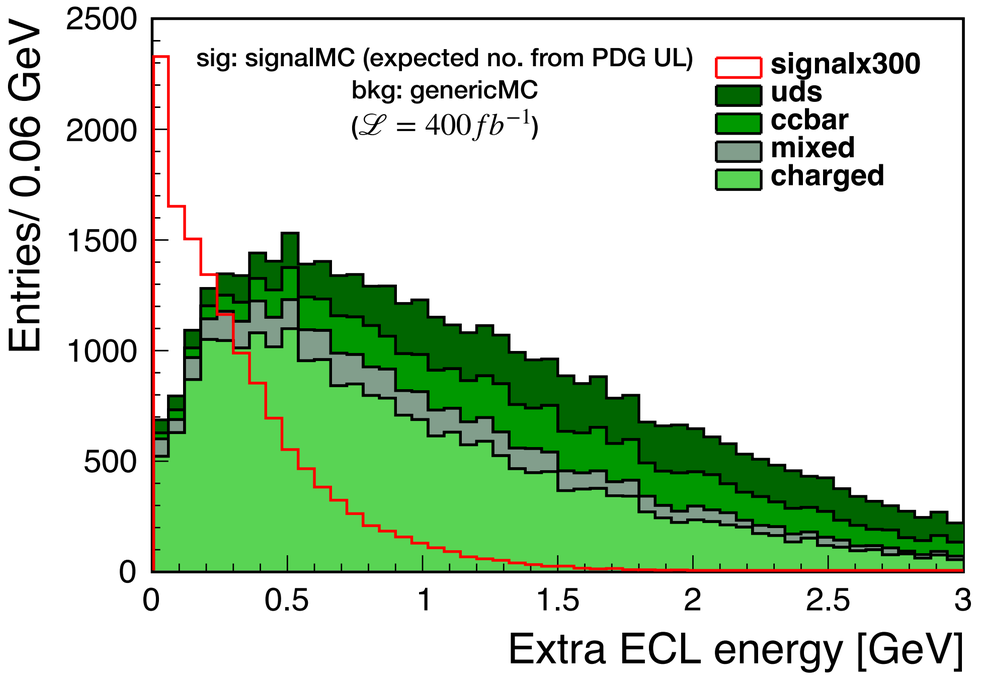
- Reconstruct tag B meson with only hadronic decays using FEI (~1 % efficiency).

- Reconstruct signal B mesons by combining K and oppositely charged pair combinations of e, μ, π (eg: $K^+e^+\pi^-$, $K^+\mu^+e^-$,…).

- For signal, there should not be any π^0 in the rest of event of B tag meson: apply π^0 veto

- Signal extraction: narrow peak at zero in the distribution of the energy of all ECL depositions not used in the reconstruction of signal and and B tag candidates.





* samples and selections are in backup slides

Challenge 1: identifying signal

$\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$

```
ma.reconstructDecay(decayString='tau+:ch0 =direct=> e+:sel ?nu',
                    cut='',
                    dmID=0,
                    path=main)
```

- Different methods in identifying true signal candidate give different results.
- I compared between MC truth match (isSignal) and topoana.
- No. of truth matched signal events are 22 % less compared to topoana.
- For $B^+ \to J/\psi K^+$, the difference is 5 % .

"isSignal" → 3779

"isSignalAcceptedMissingNeutrino" → 3779

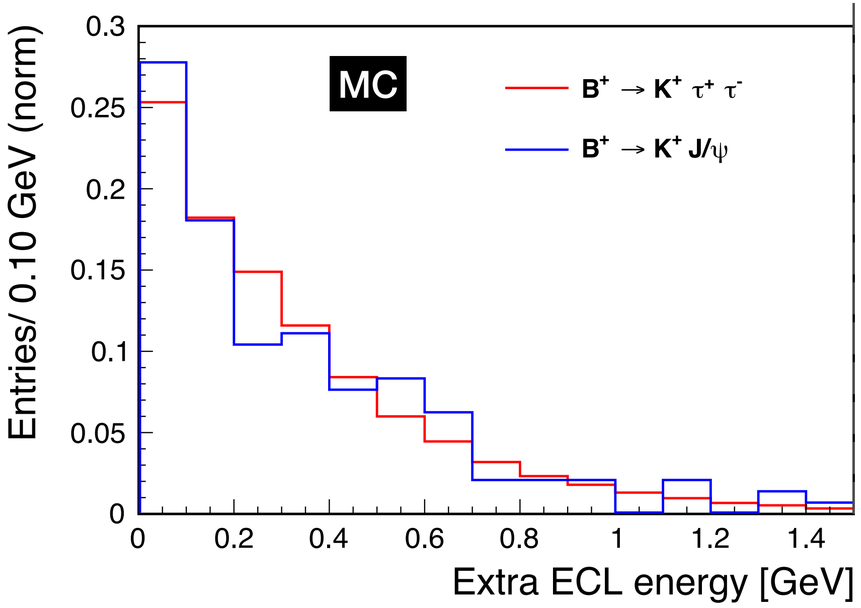
from topoana → 4849

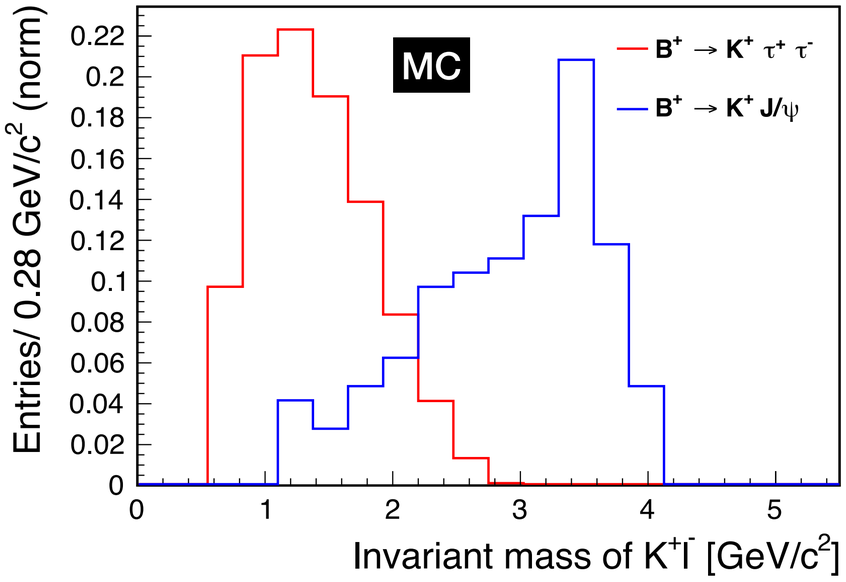
Do anyone observe this difference in other missing energy decays?

Challenge 2: suitable control channel

- Control sample with same or equivalent final states: verification of efficiency, data-MC agreement check, validation of the BDT training, etc.
- In the final state, it must have three tracks: K and oppositely charged pair combinations of e, μ, π.
- Look at $B^+ \to J/\psi K^+$ decays using hadronic tagging where $J/\psi \to l^+l^- \, (l = e, \mu)$
- Reconstruct with same selections as in case of $B^+ \to K^+\tau^+\tau^-$, except the invariant mass of leptons pair cut: $2.90 < M(l^+l^-) < 3.15\,\mathrm{Gev/c^2}$
- After π^0 veto and extra ECL energy $< 1.5\,\mathrm{GeV}$, number of signal events in MC are small: 129 ($\mathscr{L} = 364.35\,fb^{-1}$)

any suggestion for alternative control channel of higher statistics?





Challenge 1: identifying signal

- Check candidates' mcErrors where isSignal don't match with topoana.
  - mcErrors show muon and electron are mis-identified as pion
  - Still these are signal events, and I can keep them.
- What is the cause?
  - The difference between topoana and isSignal signal event number reduces from 22 % to 11 % after tight pionID cut before doing random selection

thanks Valerio and Vidya

Challenge 2: suitable control channel

rough estimation

$$B^+ \to \bar{D}^0 \pi^+$$
$$\downarrow$$
$$K^+ \pi^-$$

$$\frac{N_{D\pi}}{N_{J/\psi K}} = \frac{\epsilon' \,.\, \mathscr{B}(B^+ \to \bar{D}^0 \pi^+) \,.\, \mathscr{B}(\bar{D}^0 \to K^- \pi^+)}{\mathscr{B}(B^+ \to J/\psi K^+) \,.\, \sum_l (\mathscr{B}(J/\psi \to ll)) \,.\, \epsilon_{J/\psi \to ll}}$$

in $\mathscr{L} = 364.35\, fb^{-1}$

$N_{J/\psi K} = 129$

$\epsilon' = 40.55\,\%$

$\epsilon_{J/\psi \to ee} = 30.3\,\%$

$\epsilon_{J/\psi \to \mu\mu} = 27.8\,\%$

$\mathscr{B}(B^+ \to \bar{D}^0 \pi^+) \,.\, \mathscr{B}(\bar{D}^0 \to K^- \pi^+) = 1.70 \times 10^{-4}$

$\mathscr{B}(B^+ \to J/\psi K^+) = 1.02 \times 10^{-3}$

$\mathscr{B}(J/\psi \to e^+ e^-) = 5.97 \times 10^{-2}$

$\mathscr{B}(J/\psi \to \mu^+ \mu^-) = 5.96 \times 10^{-2}$

$$N_{D\pi} = 251$$

Backup slides

Sample and selections

SignalMC (for signal):

- Generated events: 50×10^6
- Generator model: BTOSLLBALL
- release-06-00-10
- globalTag: mc_production_MC15ri_a
- bkg:early phase III (release-06-00-05), BGx1

GenericMC (for background):

- Generated events: MC15rib
  Luminosity $= 400 fb^{-1}$

Global tag:

- analysis_tools_light-2205-abys

Charged tracks (e, μ, K, π) cuts:

- transverse distance from IP, $dr < 0.5$
- distance in beam direction from IP, $|dz| < 2$
- polar angle is with in CDC acceptance (thetaInCDCAcceptance)
- Kaon binary PID, $\mathscr{L}(K/\pi) > 0.6$
- Electron PID, $\mathscr{L}(e) > 0.9$
- Muon PID, $\mathscr{L}(\mu) > 0.9$

Sample and selections

Reconstruct FEI hadronic B_{tag}:

- weight file prefix - 'FEIv4_2022_MC15_light-2205-abys'
- Two most probable B_{tag} candidates are accepted
- $M_{bc} > 5.27$
- $|\Delta E| < 0.1$
- FEI signal probability > 0.001
- ROE of B_{tag} has 3 charged tracks

Continuum suppression:

- event sphericity > 0.2
- cosTBTO < 0.9

ROE mask:

- $dr < 0.5$, $|dz| < 2$, thetaInCDCAcceptance
- clusterNHits > 1.5
- $E > 0.080$ GeV (FWD), > 0.030 (BRL), > 0.060 (BWD)
- $|$cluster time$| < 200$
- minC2TDist > 20
- $\left|\frac{\text{cluster time}}{\text{clusterErrorTiming}}\right| < 2.0$

π^0 veto:

- Cut on ROE π^0: $120 < \text{M} < 150\,\text{MeV/c}^2$
- Select one π^0 per event that has the nearest mass to the PDG mass

Best candidate selection

- Randomly select a candidate in an event among the highest FEI signal probability candidates

Sample and selections

$B^+ \to J/\psi K^+$

GenericMC:

- Generated events: MC15rib
  Luminosity $= 400\, fb^{-1}$

Data:

- Proc 13 + Moriond2023_prompt (exp 20-26)
  Luminosity = $364.35\, fb^{-1}$

Global tag:

- analysis_tools_light-2205-abys
- data_beam_conditions_proc13prompt (data)

Charged tracks (e, μ, K, π) cuts:

- transverse distance from IP, $dr < 0.5$
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- Kaon binary PID, $\mathscr{L}(K/\pi) > 0.6$
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J/ψ mass window cut:

- $2.90 < M(l^+l^-) < 3.15\,\mathrm{GeV/c^2}$

Only difference compare to signal sample reconstruction

Sample and selections

$B^+ \to J/\psi K^+$

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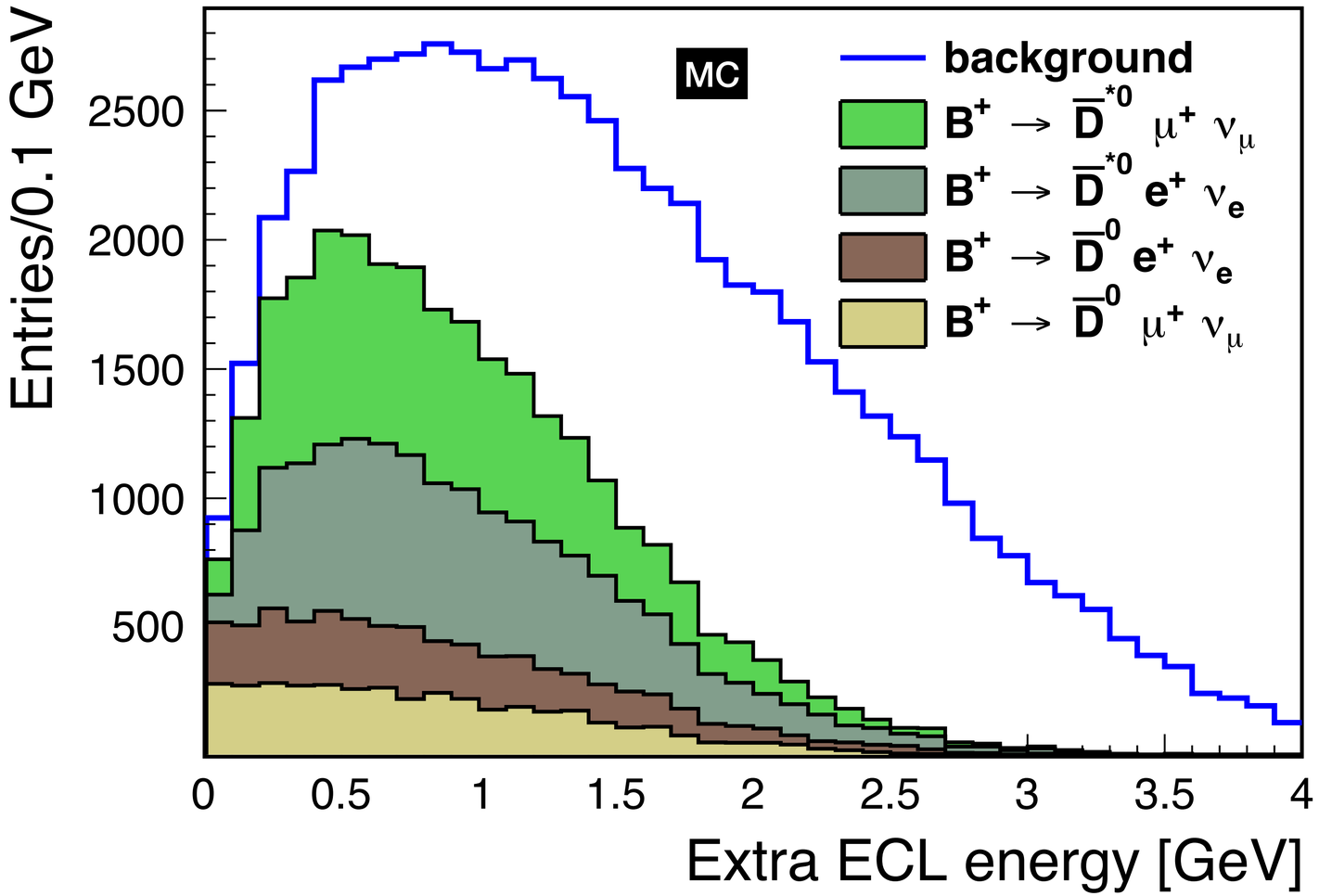
Charged decay modes

$B^+ \to K^+\tau^+\tau^-$

background=> generic charged MC (MC15rib,400fb^{-1})



- $B^+ \to \bar{D}^{*0} l^+ \nu_l$ and $B^+ \to \bar{D}^0 l^+ \nu_l$ are the main source of backgrounds in B^+B^- samples