FEI Performance, $B^+ \to \rho^0 \mu^+ \nu_\mu$, $B^+ \to \tau^+ \nu_\tau$

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Overview

- Primary aim to compare the performance of the specific and generic FEI in the context of charmless SL decays. $B^+ \to \rho^0 \mu^+ \nu_\mu$ chosen as a working example
- Key performance indicator: number of correctly reconstructed $\Upsilon(4S)$ candidates
- As mentioned in previous updates, have been observing a lower performance of the specific FEI compared with the generic for this decay mode
- Main focus currently is trying to investigate this behaviour

Training Samples, FEIv4, $B^+ \to \rho^0 \mu^+ \nu_\mu$

The specific FEI was trained on the following MC (all BGx1):

- 90M generic mixed background events: MC7 phase III.
- 90M generic charged background events: MC7 phase III.
- 100M $\Upsilon(4S) \to B^+_{sig} B^-$ events, $B^+_{sig} \to \rho^0 \mu^+ \nu_\mu$: Generated myself.
- 4M $B^+ \to$ ulnu charged background events: MC7 phase III.
- 3M $B^0 \to$ ulnu mixed background events: MC7 phase III.

The generic FEI was trained (by *T. Keck*) on the following MC (all BGx1):

- 90M generic mixed background events: MC7 phase III.
- 90M generic charged background events: MC7 phase III.

Applying the FEI: Signal $B^+ \to \rho^0 \mu^+ \nu_\mu$ Sample

- Applied both specific and generic FEI to a $B^+ \to \rho^0 \mu^+ \nu_\mu$ skim on MC7 phase III $B^+ \to ulnu$. 159579 events (BGx1)
- Relevant B_{sig} selections included:
  - $0.5 < M_{\pi\pi} < 1.4$ GeV
  - -1.0 < Corrected ΔE < 2.0 GeV
  - 5.0 < Corrected Mbc < 5.3 GeV
  - + PID cuts, cleaning ROE... (*see back-up slides for details*)
- Best candidate selection on $\Upsilon(4S)$ using B_{tag} signal probability $\to$ one per event

Performance Indicators

$$\text{Efficiency} = \frac{\#\text{ events with reconstructed candidates}}{\#\text{ total events}}$$

$$\text{Purity} = \frac{\#\text{ events with correct* candidates}}{\#\text{ events with reconstructed candidates}}$$

*isSignal == 1

$$\text{Reconstruction Efficiency (correct)} = \frac{\#\text{ events with correct* candidates}}{\#\text{ total events}}$$

Comparing the FEI: Signal $B^+ \to \rho^0 \mu^+ \nu_\mu$ Sample

Generic FEI

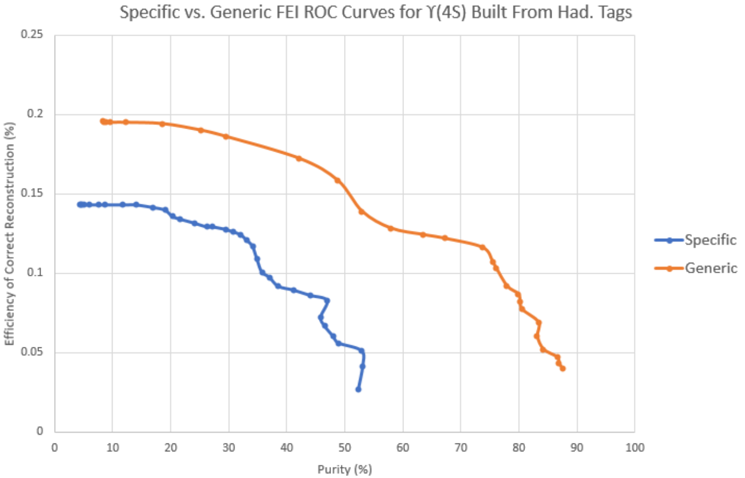
* isSignal == 1	B_{sig}	B_{had}	$\Upsilon(4S)_{had}$	B_{SL}	$\Upsilon(4S)_{SL}$	$\Upsilon(4S)_{all}$
N_{events}	159579	122981		36598		159579
No. of reconstructed candidates	139842	272641	2925	1791048	22286	22875
No. of correct* candidates	33709	2101	241	2435	387	614
Efficiency			**2.38%**		**60.9%**	**14.3%**
Purity			**8.24%**		**1.74%**	**2.68%**
Reconstruction Efficiency (correct)			**0.196%**		**1.06%**	**0.385%**

Specific FEI

* isSignal == 1	B_{sig}	B_{had}	$\Upsilon(4S)_{had}$	B_{SL}	$\Upsilon(4S)_{SL}$	$\Upsilon(4S)_{all}$
N_{events}	159579	122981		36598		159579
No. of reconstructed candidates	139842	78004	4477	1720160	36569	36990
No. of correct* candidates	33709	865	199	673	354	529
Efficiency			**3.64%**		**99.9%**	**23.2%**
Purity			**4.44%**		**0.968%**	**1.43%**
Reconstruction Efficiency (correct)			**0.162%**		**0.967%**	**0.331%**

- Shown previously at F2F meeting. Generic FEI outperforming specific FEI $\to$ why?

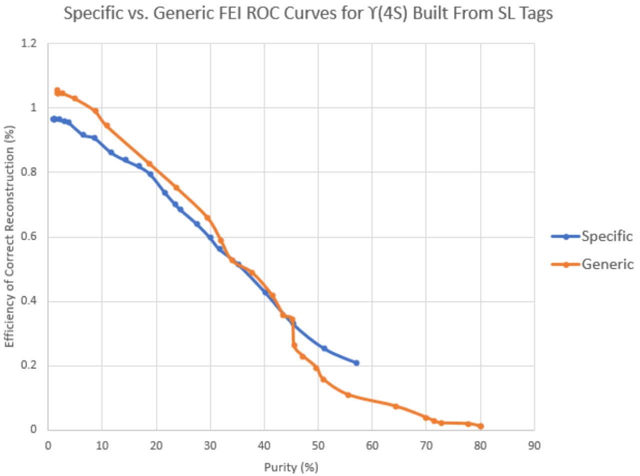
ROC Curves: Signal $B^+ \to \rho^0 \mu^+ \nu_\mu$ Sample, Hadronic Tag



- Generic FEI consistently outperforming specific at all values of SignalProbability for hadronic tags

$$\text{Reconstruction Efficiency (correct)} = \frac{\#\text{ events with correct* candidates}}{\#\text{ total events}}$$

ROC Curves: Signal $B^+ \to \rho^0 \mu^+ \nu_\mu$ Sample, SL Tag

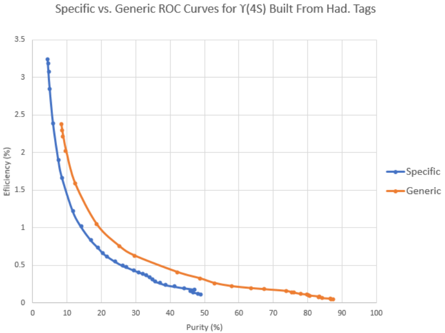


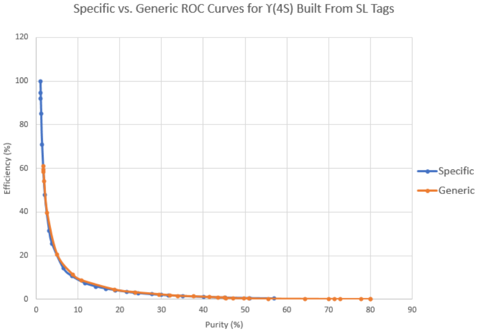
- Specific FEI reaches generic performance for SL tags only at high purities

$$\text{Reconstruction Efficiency (correct)} = \frac{\#\ \text{events with correct* candidates}}{\#\ \text{total events}}$$

ROC Curves: Signal $B^+ \to \rho^0 \mu^+ \nu_\mu$ Sample

- Alternative ROC curves displaying efficiency vs. purity show similar trends.





$$\text{Efficiency} = \frac{\#\text{ events with reconstructed candidates}}{\#\text{ total events}}$$

FEI Performance for $B^+ \to \tau^+\nu_\tau$

- Given low observed specific FEI performance for $B^+ \to \rho^0\mu^+\nu_\mu$ with Belle II MC, aim was to replicate only other known comparison of specific and generic FEI on Belle II MC $\to$ T. Keck's Masters thesis
- $B^+ \to \tau^+\nu_\tau$, $\tau^+ \to \mu^+\nu_\mu\bar{\nu_\tau}$. Analysis with **no beam background**
- **Under-trained** specific FEI (20M signal events instead of recommended order of 100M) still out-performed generic for both hadronic and SL tags
- Repeated existing comparative study with some caveats: FEIv4 vs. FEIv3 etc. *See back-up slides for details*

FEI Performance for $B^+ \to \tau^+ \nu_\tau$

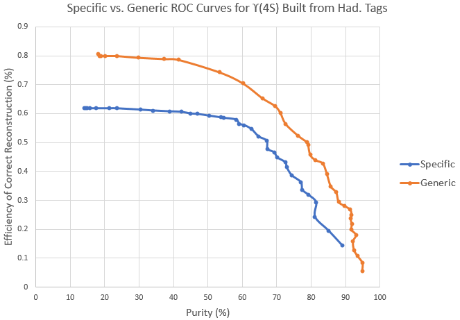
Generic FEI

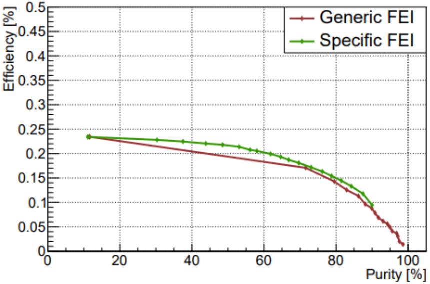
* isSignal == 1	B_{sig}	B_{had}	$\Upsilon(4S)_{had}$	B_{SL}	$\Upsilon(4S)_{SL}$	$\Upsilon(4S)_{all}$
N_{events}	90000	67139		22861		90000
No. of reconstructed candidates	175367	28796	2994	539147	16740	17903
No. of signal candidates	63928	1807	542	2031	1090	1618
Efficiency			**4.46%**		**73.2%**	**19.9%**
Purity			**18.1%**		**6.51%**	**9.04%**
Reconstruction Efficiency (correct)			**0.807%**		**4.77%**	**1.80%**

Specific FEI

* isSignal == 1	B_{sig}	B_{had}	$\Upsilon(4S)_{had}$	B_{SL}	$\Upsilon(4S)_{SL}$	$\Upsilon(4S)_{all}$
N_{events}	90000	67139		22861		90000
No. of reconstructed candidates	175367	19675	3430	511491	19710	20934
No. of correct* candidates	63928	1576	488	1504	1096	1525
Efficiency			**5.11%**		**86.2%**	**23.3%**
Purity			**14.2%**		**5.56%**	**7.28%**
Reconstruction Efficiency (correct)			**0.727%**		**4.79%**	**1.69%**

ROC Curves: Signal $B^+ \to \tau^+\nu_\tau$ Sample, Hadronic Tag





(b) Hadronic B channels.

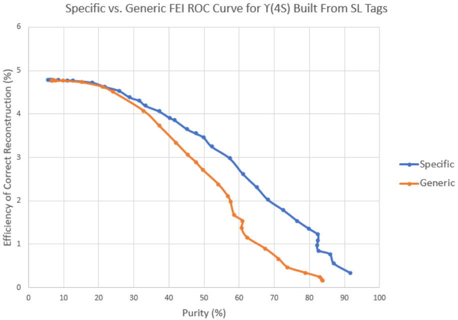
My Analysis

T. Keck, *IEKP-KA-2014-18*

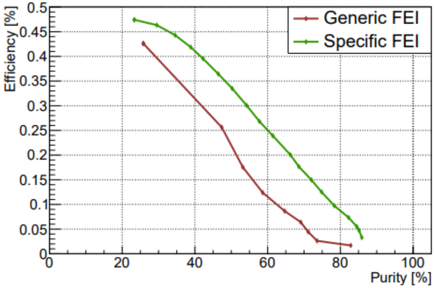
- No good agreement between analyses for hadronic tags. Specific FEI does not reach generic performance
- Efficiencies observed in my own analysis significantly higher than T. Keck's, at all purities

$$\text{Reconstruction Efficiency (correct)} = \frac{\text{\# events with correct* candidates}}{\text{\# total events}}$$

ROC Curves: Signal $B^+ \to \tau^+ \nu_\tau$ Sample, SL Tag



My Analysis



(a) Semileptonic B channels.

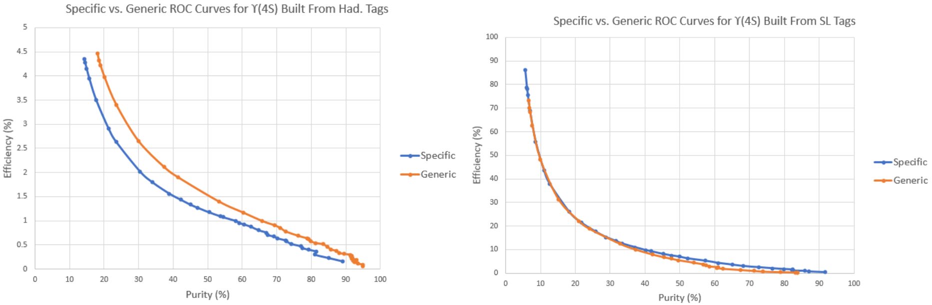
T. Keck, *IEKP-KA-2014-18*

- Specific FEI outperforms generic for SL tags in both analyses, despite being under-trained
- Again, much higher efficiencies observed in my analysis than T. Keck's, at all purities

$$\text{Reconstruction Efficiency (correct)} = \frac{\#\text{ events with correct* candidates}}{\#\text{ total events}}$$

ROC Curves: Signal $B^+ \to \tau^+ \nu_\tau$ Sample

- Alternative ROC curves displaying efficiency vs. purity show similar trends



$$\text{Efficiency} = \frac{\#\text{ events with reconstructed candidates}}{\#\text{ total events}}$$

Conclusions/Ongoing Work

- Specific FEI trained on recommended sample sizes for decay mode $B^+ \to \rho^0 \mu^+ \nu_\mu$ consistently under-performs compared with generic FEI
- Best respective performance when using SL tags, allowing specific FEI performance to reach generic only at high values of SignalProbability
- Even an under-trained specific FEI can outperform the generic for SL-tagged $B^+ \to \tau^+ \nu_\tau$, though this was not observed for hadronic tags $\to$ does the specific FEI work better for some decay modes over others?
- Currently working on re-training the specific FEI for $B^+ \to \tau^+ \nu_\tau$ on the "recommended" sample size (100M signal events) to investigate potential improvement for hadronic channels

All suggestions are welcome!

Back-up: Selections Made in Applied FEI, $B^+ \to \rho^0 \mu^+ \nu_\mu$

- Initial skim to save computing time, max 12 tracks in event: nCleanedtracks $\leq$ 12, where cleaned tracks have distances dr $<$ 2 cm, $|$dz$|$ $<$ 4 cm
- Cut on number of allowed tracks from B_{sig}: Bextracut = nRemainingTracksInEvent $\geq$ 3, nRemainingTracksInEvent $\leq$ 7
- μ_{sig} cuts: muon identification probability muid $>$ 0.5, track distances dr $<$ 1 cm, $|$dz$|$ $<$ 2 cm
- π_{sig} cuts: pion identification probability piid $>$ 0.5, track distances dr $<$ 1 cm and $|$dz$|$ $<$ 2 cm, momentum 0.5 $<$ useCMSFrame(p) $<$ 2.8 GeV
- Cut on ρ^0_{sig} mass: 0.5 $<$ M $<$ 1.4 GeV
- Cleaning RestOfEvent: 'dr $<$ 2 and $|$dz$|$ $<$ 4', 'clusterE9E25 $>$ 0.9, clusterTiming $<$ 50, goodGamma == 1, trackMatchType==0'
- Cut on beam-constrained mass and energy difference, corrected with neutrino missing momentum for B_{sig}: -1.0 $<$ sigDE $<$ 2.0 GeV, 5.00 $<$ sigMbc $<$ 5.30 GeV
- Choosing only one candidate per event with highest B_{tag} sigProb for $\Upsilon(4S)$

Back-up: $B^+ \to \tau^+ \nu_\tau$

FEI applied to $\tau^+ \to \mu^+ \nu_\mu \bar{\nu_\tau}$ skim of MC7 BGx0 phase III signal $B^+ \to \tau^+ \nu_\tau$ sample, $N_{events} = 90000$ with following selections:

- Initial skim to save computing time, max 12 tracks in event: nCleanedtracks $\leq$ 12, where cleaned tracks have distances dr $<$ 2 cm, |dz| $<$ 4 cm
- μ_{sig} cuts: muon identification probability muid > 0.6
- Clean ROE for Υ(4S): dr $<$ 2 cm, |dz| $<$ 4 cm
- nROETracks == 0 for Υ(4S) ROE
- Choosing only one candidate per event with highest B_{tag} sigProb for $\Upsilon(4S)$

My Analysis

- FEIv4, (release-01-00-03)
- Specific training:90M charged, 90M mixed, 20M signal $B^+ \to \tau^+ \nu_\tau$
  Generic training: Unknown sample size used for BGx0 training. Either 50M or 90M each of charged and mixed
- MC7 study, BGx0

T. Keck's Analysis

- FEIv3, (release-unknown (older))
- Specific training: 20M charged, 20M mixed, 20M signal $B^+ \to \tau^+ \nu_\tau$
  Generic training: 50M charged, 50M mixed.
- MC production unknown, older than MC7, BGx0