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

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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
- Study the effect of a signal-dependent training method for event reconstruction
- Have trained the specific FEI using a 30M $B^+ \to \rho^0 \mu^+ \nu_\mu$ sample $\to$ generated myself and validated using MC7 signal samples
- Generic FEI training taken from KEKCC:

  /home/belle2/tkeck/feiv4/Belle2_2017_MC7_Track14_2/

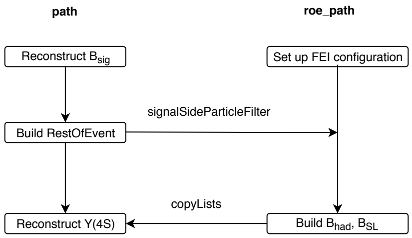
- Key performance indicator: number of correctly reconstructed $\Upsilon(4S)$ candidates

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

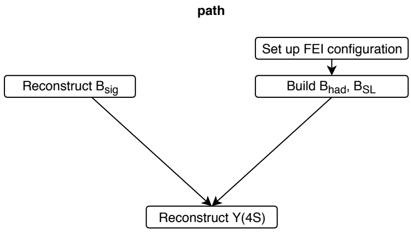
- Specific FEI was trained on the following MC:
  - 50M generic mixed background events: MC7 phase III *prod00000786*. BGx1
  - 50M generic charged background events: MC7 phase III *prod00000788*. BGx1
  - 30M $\Upsilon(4S) \to B^+_{sig} B^-$ events, $B^+_{sig} \to \rho^0 \mu^+ \nu_\mu$: Generated myself. BGx1
- Generic FEI was trained (by *T. Keck*) on the following MC:
  - 90M generic mixed background events: MC7 phase III *prod00000786*. BGx1
  - 90M generic charged background events: MC7 phase III *prod00000788*. BGx1
- No continuum $\to$ continuum suppression can be trained independently (future work)

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

- Performed a $B^+ \to \rho^0 \mu^+ \nu_\mu$ skim on MC7 phase III $B^+ \to$ *ulnu* sample, *prod00000852* $\to$ 159579 events (BGx1)
- Applied both specific and generic FEI to the above skim



Specific FEI



Generic FEI

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

- Same selections used in application of specific and generic FEI
- B_{sig} reconstruction identical for the two methods. Relevant selections included:
  - $0.5 < M_{\pi\pi} < 1.4$ GeV
  - -1.0 $<$ Corrected $\Delta E < 2.0$ GeV
  - 5.0 $<$ Corrected Mbc < 5.3 GeV
  - + PID cuts, cleaning ROE... (*see back-up slides for details*)
- Full $\Upsilon(4S)$ reconstruction using hadronic and SL tags $\to$ best candidate selection on $\Upsilon(4S)$ using B_{tag} signal probability $\to$ one candidate per event

Comparing the Specific and Generic FEI

Generic FEI, $N_{events} = 159579$

	B_{sig}	B_{had}	$\Upsilon(4S)_{had}$	B_{SL}	$\Upsilon(4S)_{SL}$	$\Upsilon(4S)_{all}$
No. of reconstructed candidates	139842	272641	2925	1791048	22286	22875
No. of signal* candidates	33709	2101	241	2435	387	614
Reconstruction efficiency						**0.385%**

Specific FEI, $N_{events} = 159579$

	B_{sig}	B_{had}	$\Upsilon(4S)_{had}$	B_{SL}	$\Upsilon(4S)_{SL}$	$\Upsilon(4S)_{all}$
No. of reconstructed candidates	139842	3238	582	39230	3324	3484
No. of signal* candidates	33709	137	42	180	119	150
Reconstruction efficiency						**0.094%**

$$\text{Reconstruction efficiency} = \frac{\#\text{ events with correct* candidates}}{\#\text{ total events}}$$

*B_{sig}, B_{SL}, $\Upsilon(4S)$: isSignalAcceptMissingNeutrino$\rightarrow$ truth matched, allow missing intermediate resonance, FSR and ν

B_{had}: isExtendedSignal $\rightarrow$ truth matched, allow missing intermediate resonances, FSR and FSP misidentification

Improving the Specific FEI Training: Including $b \rightarrow ulnu$ Background

- Generic FEI outperforming the specific by a factor of 4! Why?
- Improve the specific training $\rightarrow$ include background from other $b \rightarrow ulnu$ decays
- The specific FEI was re-trained on the following MC:
  - 50M generic mixed background events: MC7 phase III *prod00000786*. BGx1
  - 50M generic charged background events: MC7 phase III *prod00000788*. BGx1
  - 30M $\Upsilon(4S) \rightarrow B^+_{sig} B^-$ events, $B^+_{sig} \rightarrow \rho^0 \mu^+ \nu_\mu$: Generated myself. BGx1
  - 4M $B^+ \rightarrow$ ulnu charged background events: MC7 phase III, *prod00000852*. BGx1
  - 3M $B^0 \rightarrow$ ulnu mixed background events: MC7 phase III, *prod00000854*. BGx1
- The results of the new training were applied to the same $B^+_{sig} \rightarrow \rho^0 \mu^+ \nu_\mu$ skim, with the same event selections

Specific FEI Performance, ulnu-included Training

Specific FEI, ulnu-included training, $N_{events} = 159579$

	B_{sig}	B_{had}	$\Upsilon(4S)_{had}$	B_{SL}	$\Upsilon(4S)_{SL}$	$\Upsilon(4S)_{all}$
No. of reconstructed candidates	139842	3270	630	27066	3312	3484
No. of signal candidates	33709	143	53	171	119	160
Reconstruction Efficiency (correct)						**0.100%**

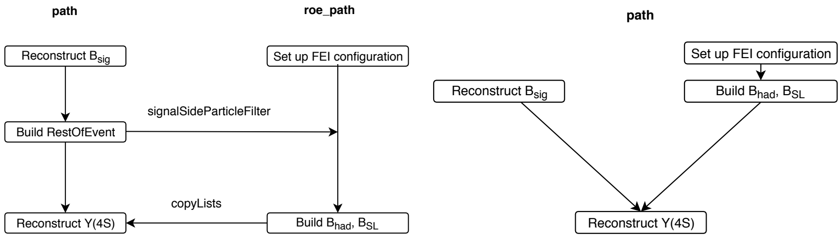
Specific FEI, ulnu-included training, no ρ^0, B_{sig} **cuts,** $N_{events} = 159579$

	B_{sig}	B_{had}	$\Upsilon(4S)_{had}$	B_{SL}	$\Upsilon(4S)_{SL}$	$\Upsilon(4S)_{all}$
No. of reconstructed candidates	832869	8147	1147	139825	6638	6866
No. of signal candidates	41154	224	56	274	144	188
Reconstruction Efficiency (correct)						**0.118%**

- Slight improvement to specific FEI performance, but still not comparable to generic FEI. Generic Eff. 0.385%
- Maximum possible reconstruction efficiency found for specific FEI when removing all ρ^0, B_{sig} cuts $\rightarrow$ still not comparable to generic FEI which includes them!

FEI Training: the Effect of the Weight Files

- Training the FEI produces weight files which are then used in the FEI application → different weights for different trainings
- Method of applying the FEI is also different between specific and generic → can we isolate whether the low specific performance is related to the method or the results of the training?
- What happens if we swap the weight files for the two methods?



Specific FEI

Generic FEI

FEI Training: the Effect of the Weight Files

Generic FEI, specific weights, $N_{events} = 159579$

	B_{sig}	B_{had}	$\Upsilon(4S)_{had}$	B_{SL}	$\Upsilon(4S)_{SL}$	$\Upsilon(4S)_{all}$
No. of reconstructed candidates	139842	252234	2748	1740319	24881	25490
No. of signal candidates	33709	1763	163	2080	307	442
Reconstruction Efficiency (correct)						**0.277%**

Generic FEI, specific weights (from ulnu-included training), $N_{events} = 159579$

	B_{sig}	B_{had}	$\Upsilon(4S)_{had}$	B_{SL}	$\Upsilon(4S)_{SL}$	$\Upsilon(4S)_{all}$
No. of reconstructed candidates	139842	296192	3048	1734195	24463	25115
No. of signal candidates	33709	1961	196	2064	324	499
Reconstruction Efficiency (correct)						**0.313%**

Specific FEI, generic weights, $N_{events} = 159579$

	B_{sig}	B_{had}	$\Upsilon(4S)_{had}$	B_{SL}	$\Upsilon(4S)_{SL}$	$\Upsilon(4S)_{all}$
No. of reconstructed candidates	139842	25669	3388	723970	31844	32189
No. of signal candidates	33709	680	240	620	384	610
Reconstruction Efficiency (correct)						**0.382%**

FEI Training: the Effect of the Weight Files

- The standard generic FEI (using the generic weights) is comparable to using the generic weights with the specific FEI method
- However, the specific weights perform better within the generic FEI framework than they do in the specific!
- Even then, this still doesn't reach the performance of the standard generic FEI

A Further Test - Updating ParticleID Cuts

- Investigated whether harsher PID cuts on B_{sig} FSPs would have any effect on specific training and application compared with the generic
- Specific FEI was re-trained on same MC (including $b \rightarrow ulnu$) and applied, but with PID cuts changed from >0.5 to >0.8 (*see back-up slides for details*) $\rightarrow$ generic still outperforming specific

Specific FEI, PID training, $N_{events} = 159579$

	B_{sig}	B_{had}	$\Upsilon(4S)_{had}$	B_{SL}	$\Upsilon(4S)_{SL}$	$\Upsilon(4S)_{all}$
No. of reconstructed candidates	108696	2322	462	24786	2619	2796
No. of signal candidates	29795	87	36	143	116	152
Reconstruction Efficiency (correct)						**0.095%**

Generic FEI, new PID cuts, $N_{events} = 159579$

	B_{sig}	B_{had}	$\Upsilon(4S)_{had}$	B_{SL}	$\Upsilon(4S)_{SL}$	$\Upsilon(4S)_{all}$
No. of reconstructed candidates	108696	35361	317	224124	2382	19524
No. of signal candidates	29795	255	30	322	41	539
Reconstruction Efficiency (correct)						**0.338%**

FEI Performance: Backgrounds

- So far have only discussed the FEI performance on a signal sample
- Applied the generic and specific FEI (with $b \to$ *ulnu*-included training) to the following background samples:
  - 90k generic mixed background events: MC7 phase III *prod00000786*. BGx1
  - 90k generic charged background events: MC7 phase III *prod00000788*. BGx1
  - 570k $\Upsilon(4S) \to B^+B^-$ events, $B^+ \to$ other ulnu: skimmed from MC7 phase III $B^+ \to$ *ulnu* sample, *prod00000852*. BGx1

FEI Performance: Backgrounds

Specific FEI, ulnu-included training

		B_{sig}	B_{had}	$\Upsilon(4S)_{had}$	B_{SL}	$\Upsilon(4S)_{SL}$	$\Upsilon(4S)_{all}$
mixed	No. of reconstructed candidates	9468	34	10	1096	101	104
charged	No. of reconstructed candidates	9741	142	27	1851	137	150
other ulnu	No. of reconstructed candidates	171912	2592	406	35409	2803	2953

Generic FEI

		B_{sig}	B_{had}	$\Upsilon(4S)_{had}$	B_{SL}	$\Upsilon(4S)_{SL}$	$\Upsilon(4S)_{all}$
mixed	No. of reconstructed candidates	9468	264726	110	825201	930	976
charged	No. of reconstructed candidates	9741	343108	161	910720	1080	1144
other ulnu	No. of reconstructed candidates	171912	1132057	2742	6336882	22435	23206

- Generic FEI reconstructs 9 times more fake $\Upsilon(4S)$ candidates than the specific FEI

mixed: $N_{events} = 90000$, charged: $N_{events} = 90000$, other ulnu: $N_{events} = 569073$

Conclusions

- Specific FEI consistently performs worse than the generic FEI in reconstructing full $\Upsilon(4S)$ decay events for $B^+ \to \rho^0 \mu^+ \nu_\mu$
- Strange behaviour observed when swapping weights for the two methods $\rightarrow$ can the specific training be further optimised?
- Specific FEI has a higher background rejection, but at the cost of too much signal loss. The performance was expected to be better in both of these areas.

Ongoing/Future Work

- Other issues I have been looking at but have not included in this talk:
  - Signal probability distribution for each individual tag channel $\rightarrow$ correlation between sigProb and isSignal?
  - Better ways of performing a best candidate selection
  - Cross-check with $B \rightarrow \tau\nu_\tau$ mode $\rightarrow$ imitating T. Keck's Masters thesis
- For completeness, should also include $B^+ \rightarrow \rho^0 e^+ \nu_e$
- Continuum suppression also needs to be trained and applied

All suggestions are welcome!

Back-up: Selections Made in Applied FEI, PID cuts >0.5

- 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 $=3 \leq$ nRemainingTracksInEvent ≤ 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: Selections Made in Applied FEI, PID cuts >0.8

- 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 $= 3 \leq$ nRemainingTracksInEvent ≤ 7
- μ_{sig} cuts: muon identification probability muid $>$ 0.8, track distances dr $<$ 2 cm, $|$dz$|$ $<$ 4 cm
- π_{sig} cuts: pion identification probability piid $>$ 0.8, track distances dr $<$ 2 cm and $|$dz$|$ $<$ 4 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
- B_{tag} sigProb $>$ 0 for B_{had}, B_{SL}
- Choosing only one candidate per event with highest B_{tag} sigProb for $\Upsilon(4S)$