Fast Inclusive Flavo(u)r Tagging at LHCb

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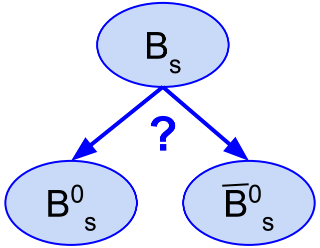
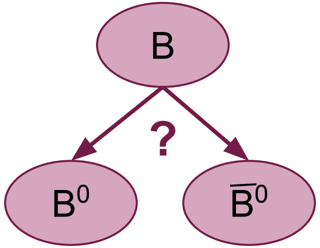
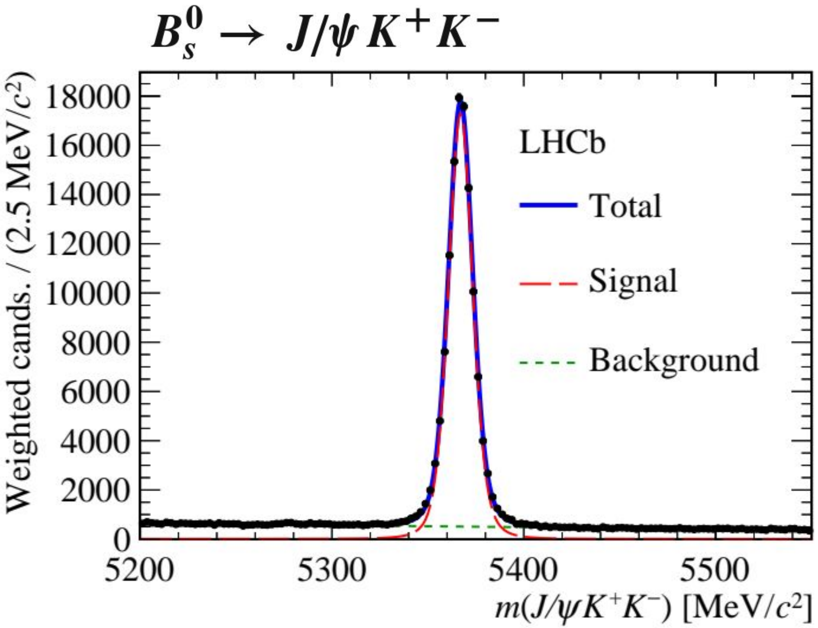
Flavour Tagging at LHCb

Determining the **flavour at production** of neutral B mesons







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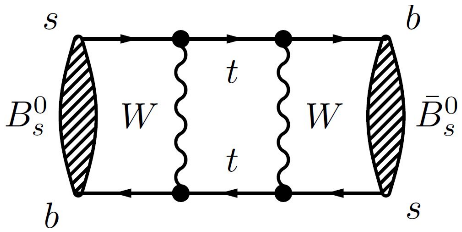
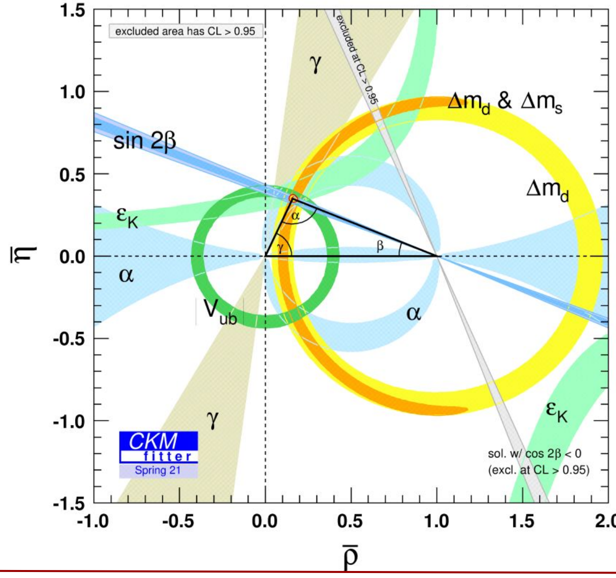
Example: B_s meson oscillation

- Neutral *s,c,b* mesons can mix into their anti-particles
- Flavour eigenstates B^0_s and $\bar{B}^0_s$ are linear combinations of the mass eigenstates B_H and B_L
- Oscillation frequency **$\Delta m_s = m_H - m_L$** provides powerful constraint on CKM triangle

$$P(t) \sim e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + C \cdot \cos(\Delta m_s t)\right]$$

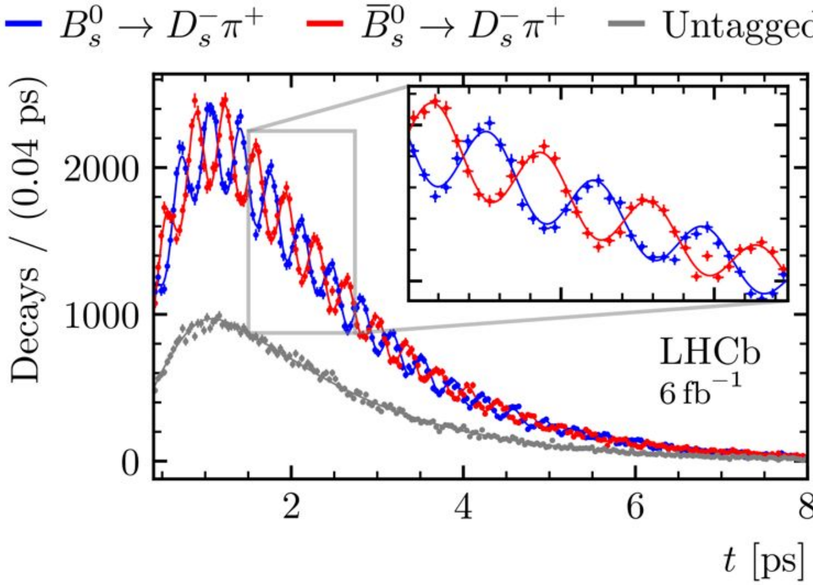




Example: B_s meson oscillation

- Reconstruct the B_s in a flavour-specific final state
- Flavour-tag the B_s at production
- Measure and fit the decay time distributions

$$P(t) \sim e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + C \cdot \cos(\boxed{\Delta m_s} t)\right]$$



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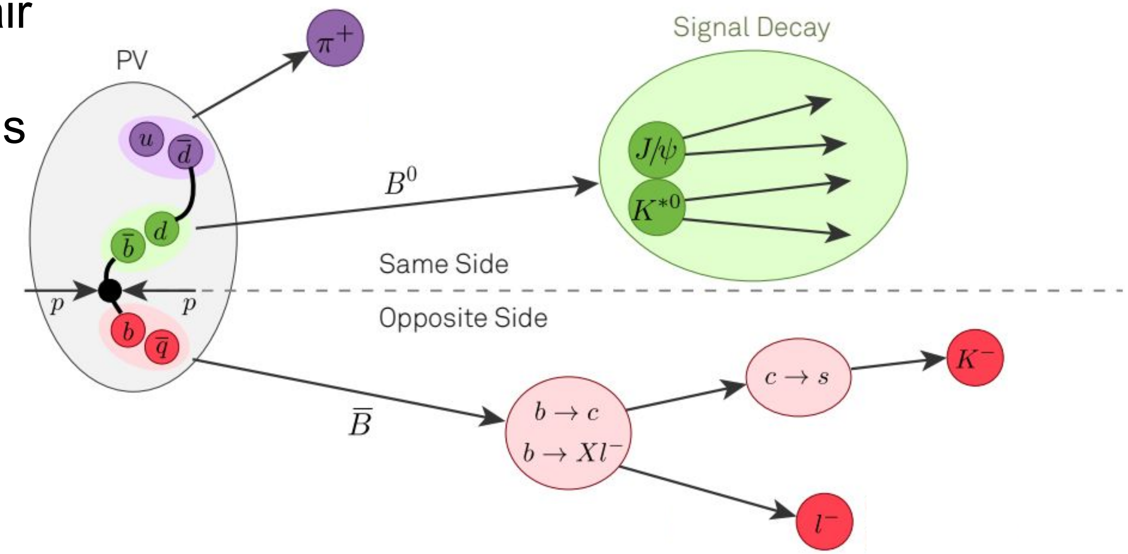
Flavour Tagging

<u>Opposite side B decay:</u>

- 24% of events have that $b\bar{b}$ pair in the LHCb acceptance
- look for decay product that tags the other (opposite side) B meson



Flavour Tagging

Opposite side B decay:

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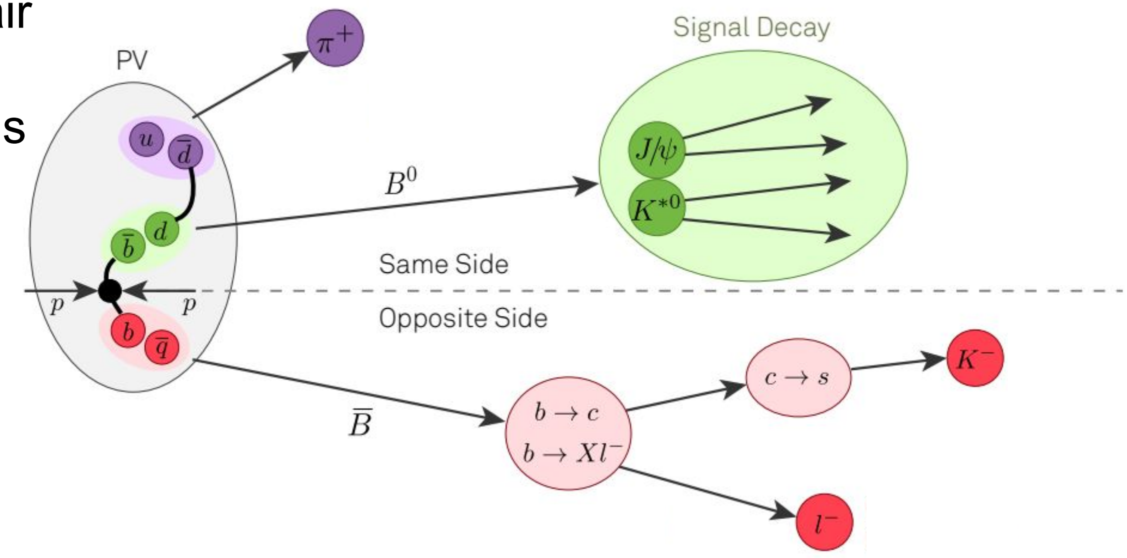
Same side information:

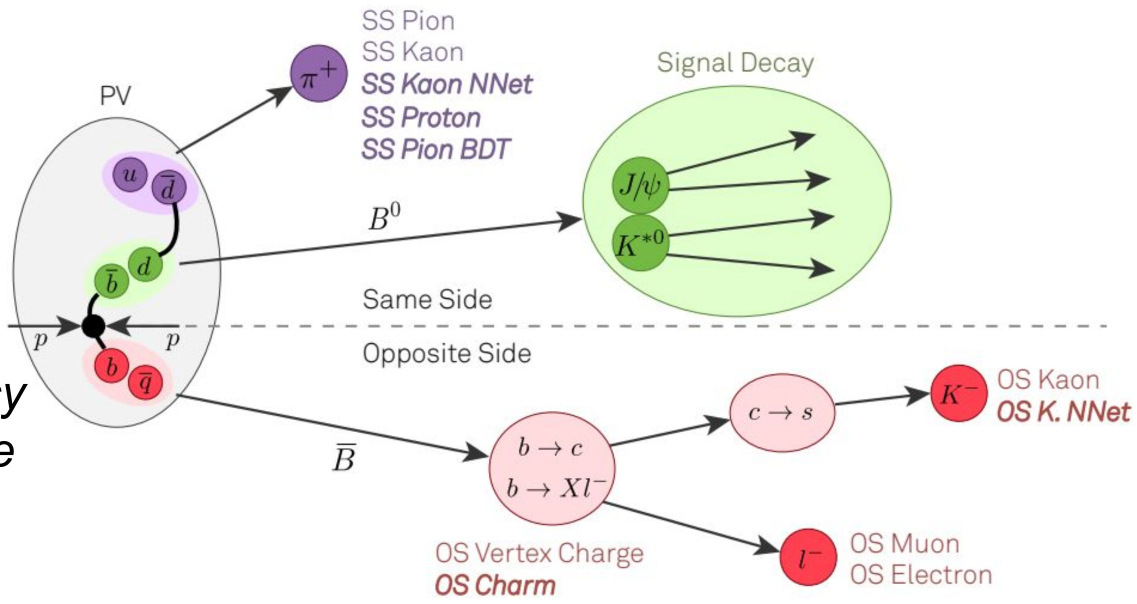
- additional particles are created during the fragmentation process
- 50% of B are accompanied by a charged pion, 50% of B_s by a charged kaon



Classical Taggers

- one tagger per final state species
- selection to find the “tagging particle”
- MVA (usually BDT) to evaluate mistag rate

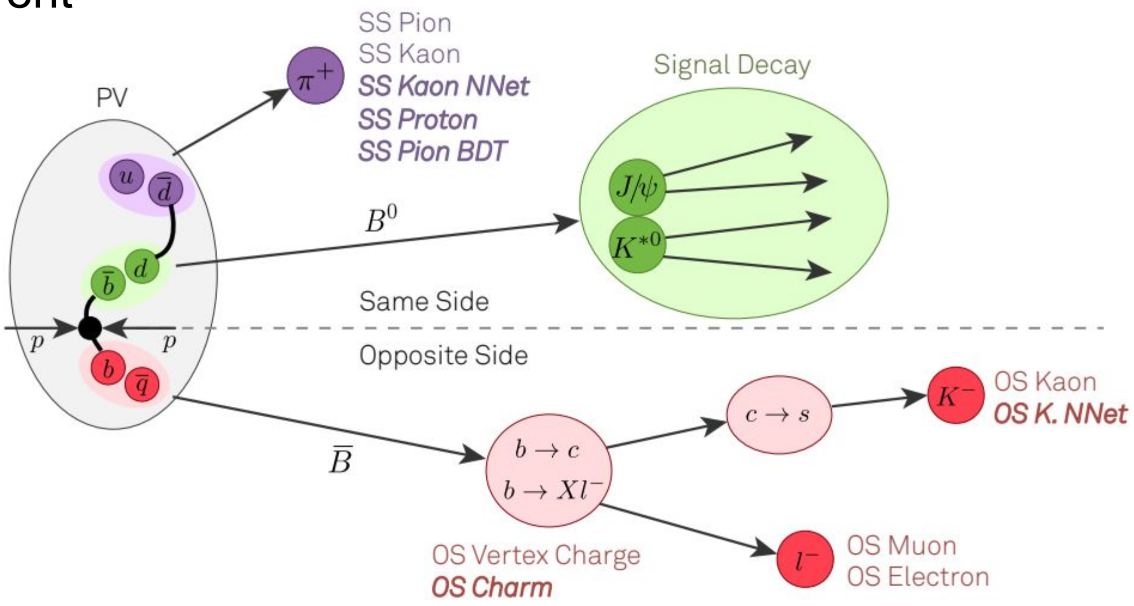
- low tagging efficiency (*efficiency that a tagging decision could be made*)
- several taggers are combined by picking the one with the smallest predicted mistag



Inclusive Taggers

- can consider all tracks in the event

Requirements:
- variable number of inputs (number of tracks varies by event)
- permutation invariant
- fast to train and apply for eventual use in real-time environment



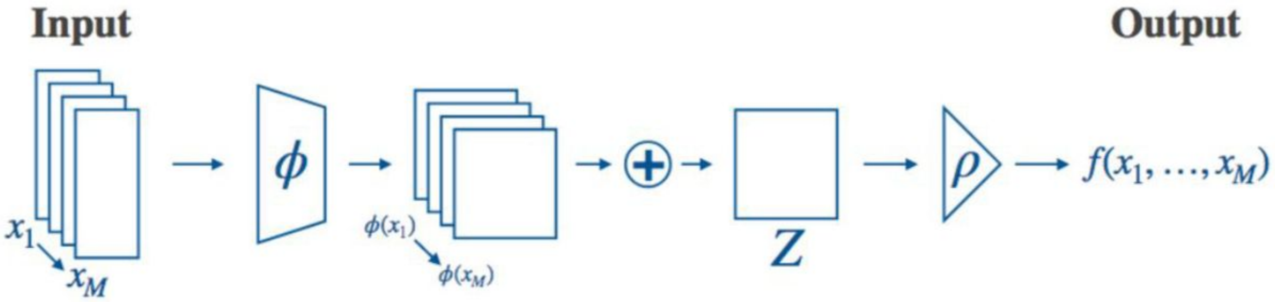
RNN inclusive tagger had good performance but was very slow to train/apply, needed input to be sorted and of fixed length

arXiv:1703.06114 [cs.LG]

DeepSet Neural Network

- “every instance (particle) is transformed (possibly by several layers) into some representation ϕ“
- “the representations ϕ are added up and the output is processed using the ρ network”

→permutation invariant, component per particle, component for entire event
→~hour to train (while RNN ~days)
→~7μs per event to evaluate (while RNN ~5h for 3M events)



Performance - metrics

Tagging efficiency ε: fraction of events that have a tagging decision (not necessarily that the tagging decision is correct)

Mistag rate/probability ω: fraction of events that have a wrong tagging decision / probability that a tagging decision is wrong

Tagging power $\varepsilon_{eff} = \varepsilon\,(1-2\cdot\omega)^2$: statistical precision of the sample

Performance - Run 2 MC

$B^0 \to J/\psi\ K^{*0}$	ε	ε_{eff}
OS Combination	38.5 %	3.81 %
SS Combination	80.1 %	1.71 %
Combination	87.0 %	**5.39 %**

$B^+ \to J/\psi\ K^+$	ε	ε_{eff}
OS Combination	38.2 %	3.94 %
SS Kaon	67.7 %	1.22
SS Pion	69.9 %	3.94 %
Combination	92.0 %	**6.39 %**

$B^0 \to J/\psi\ K^{*0}$	ε	ε_{eff}
DeepSet	100 %	**6.38 %**

$B^+ \to J/\psi\ K^+$	ε	ε_{eff}
DeepSet	100 %	**8.0 %**

$B_s \to D_s \pi^-$	ε	ε_{eff}
DeepSet	100 %	8.7 %

~ 20 - 25% increase in tagging power wrt classical taggers

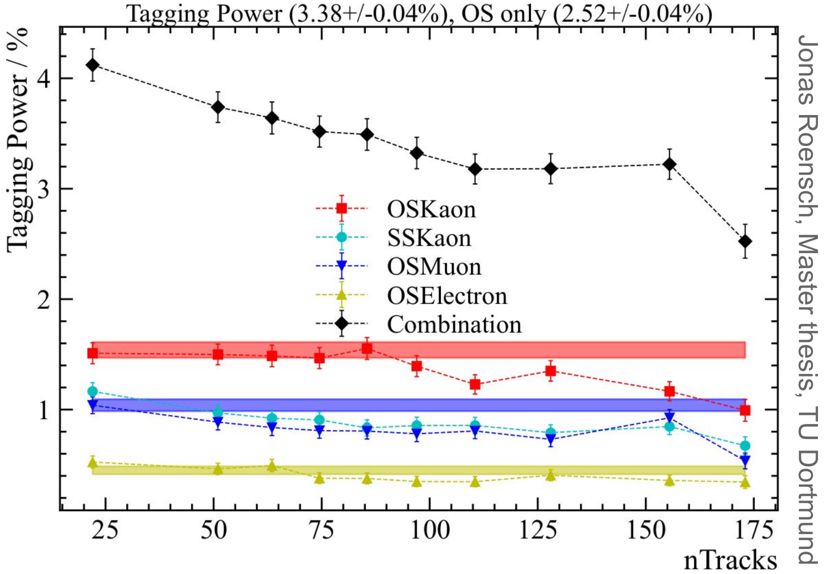
Performance - Run 3 MC

$B^+ \to J/\psi K^+$ (mu ~ 7)

Tagging algorithm	$\varepsilon_{tag}/\%$	$\bar{\omega}/\%$	$\varepsilon_{tag,eff}/\%$
OSElectron	62.25 ± 0.06	48.52 ± 0.08	0.40 ± 0.03
OSKaon	63.06 ± 0.06	44.61 ± 0.08	1.54 ± 0.03
OSMuon	57.36 ± 0.06	46.76 ± 0.09	0.81 ± 0.02
SSKaon	90.09 ± 0.04	47.13 ± 0.07	0.73 ± 0.02
SSPion	99.9983 ± 0.0017	47.1 ± 0.2	0.37 ± 0.05
SSProton	99.683 ± 0.007	46.79 ± 0.07	0.77 ± 0.04
Combination	100 ± 0	42.7 ± 0.2	3.75 ± 0.15

$B^+ \to J/\psi K^+$	ε	ε_{eff}
DeepSet	100 %	6.36 %
DeepSet presel.	100 %	6.83 %

only use particles associated to the same PV



big increase in tagging power wrt classical taggers (but classical taggers maybe not be optimally trained yet)

Summary

- Flavour tagging at LHCb is essential for meson mixing measurement and time-dependent CP violation measurements
- Flavour tagging algorithms exploits information from particles that are created with the signal particles
- DeepSet NN can take varying number of tracks, is permutation invariant, fast and yields increased performance wrt the classical taggers
- Possible improvements for Run 3 by cleaning the input
- Looking forward to testing on data :D