Implementing a graph-based approach for semi-inclusive tagging in Belle II

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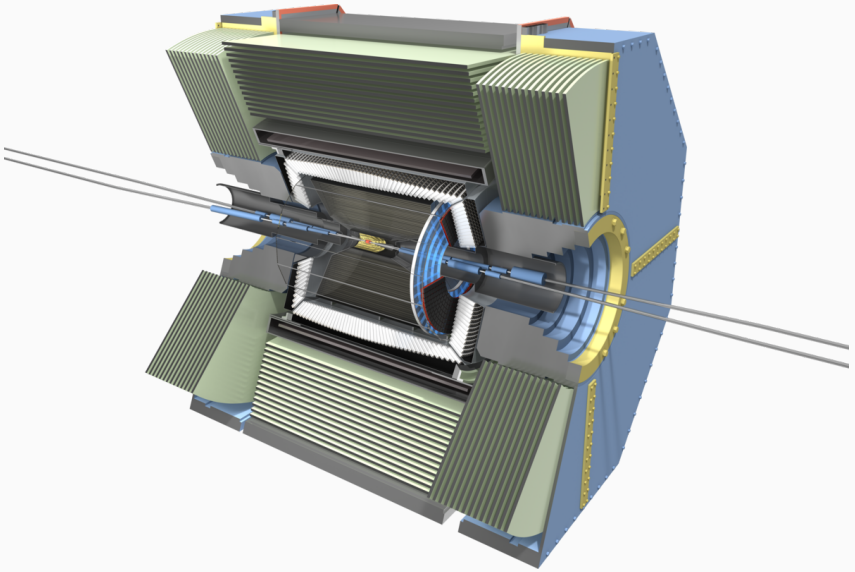
Belle II experiment

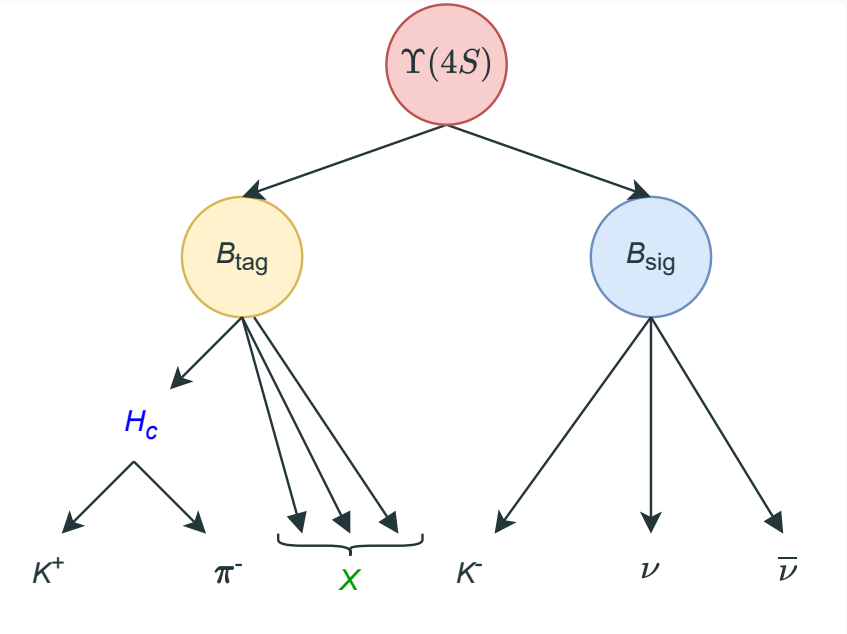
- 4π detector in Tsukuba, Japan
- collides e^- and e^+ at $\Upsilon(4S)$ resonance energy $\sqrt{s} = 10.58 GeV$
- B factory, as 96% of $\Upsilon(4S)$ decay into B meson pairs
  - B_{sig}: B decay of interest
  - B_{tag} : B which gets reconstructed to restrain the B_{sig}'s kinematics



Semi-inclusive tagging

Semi-inclusive $H_c - X$ tagging:

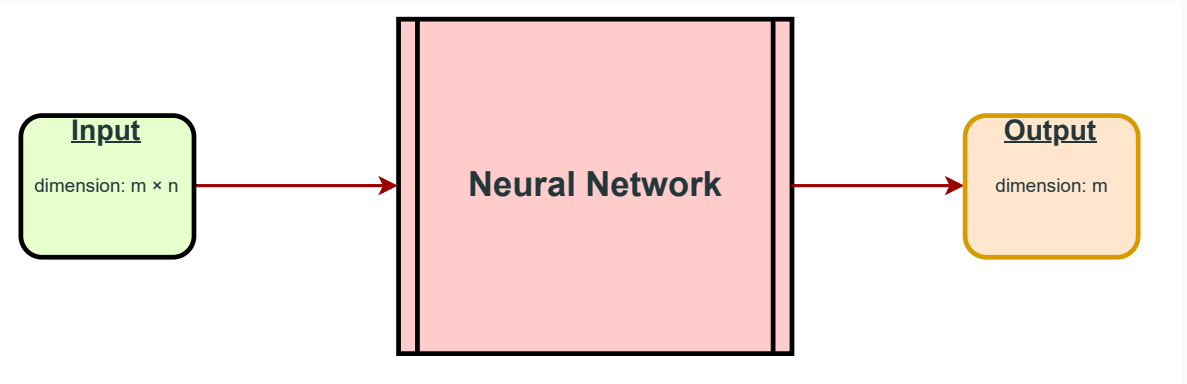
- exclusively reconstruct B_{sig}
- reconstruct a charmed hadron H_c with the FEI (BDT based Belle II reconstruction algorithm)
- reconstruct B_{tag} semi-inclusively from H_c and X (what is not used for H_c and B_{sig})



Graph based classification

Graph based neural network as final state particle classifier:

- interprets input as graph, particles are the nodes and their relations the edges
- input: 4 momentum and some particle based variables like charge, particle IDs, etc. of all FSPs later used in reconstruction
- output: classification for each particle (classes e.g. X, B_{sig} and background)



Network from *Neural relational inference for interacting systems* (PMLR 2018 2688)

Toy model results

First created $\Upsilon(4S)$ decay events on my own with `PhaseSpace` package to test the concept

- six $\Upsilon(4S)$ decay modes
- simulated background and non detected particles
- simulated momentum smearing
- etc.

Tested different separation cases:

separation case	**perfect separation**	**accuracy**
X - H_c - background	93.4%	98.4%
X - B_{sig}- background	91.9%	98.3%
X - H_c - B_{sig}- background	81.8%	97.4%

Performance on clean Belle II MC

Started to create clean training data based on MC files. Tested classification of B_{sig}, X and background for $B_{sig} \to D^* l \nu$:

- selected $D^* l \nu$ events on generator level information
- only used $D^* \to D^0 \pi$ and $D^0 \to K\, n \cdot \pi$ events
- only used events with perfectly reconstructed H_c based on MC truth information

$\Rightarrow$ graph neural network classifier performs good on this task

	0 err.	1 err.	2 err.	3 err.	≥ 4 err.	accuracy
graph NN	13.7%	17.2%	17.0%	15.3%	36.8%	76.8%
existing reco.	3.5%	9.3%	15.0%	14.8%	57.4%	72.0%

$\Upsilon(4S)$ reconstruction performance based on neural network classifier

- now the processed events are MC events with no generator level cuts on decay channels or the H_c
- semi-inclusive tagging reconstruction $\Upsilon(4S)$ based on the graph based neural network predictions

$\Rightarrow$ reconstruction suffers from low efficiency and low purity compared to already existing method for semi-inclusive $H_c - X$ tagging

	tagging efficiency	purity
graph NN	0.01%	47%
existing reco.	2.75%	70%

Outlook

For the semi-inclusive tagging another neural network architecture might improve results

The graph based classifier had good results identifying background particles, this is currently under further investigation for inclusive analyses

Back up slides I: Ablation studies

ablation case	perfect	1E	2E	3E	$\geq$ 4E	accuracy
no H_c vertex	13.7%	17.2%	17.0%	15.3%	36.8%	76.8%
no clusterReg	13.7%	17.0%	17.1%	15.1%	37.1%	76.7%
no pion ID	13.5%	17.0%	17.1%	15.3%	37.1%	76.6%
no kaon ID	13.4%	17.0%	17.3%	15.1%	37.2%	76.5%
all variables	13.4%	17.0%	17.0%	15.4%	37.3%	76.5%
no proton ID	13.6%	17.1%	16.9%	15.1%	37.4%	76.5%
no electron ID	13.3%	17.1%	17.0%	15.2%	37.5%	76.5%
no mass	13.4%	16.9%	17.1%	15.4%	37.2%	76.5%
no d_z	13.5%	16.9%	16.9%	15.1%	37.6%	76.4%
no d_r	12.9%	17.0%	16.8%	15.2%	38.0%	76.2%
no E9E21	13.2%	16.6%	17.1%	15.1%	38.0%	76.2%
no muon ID	13.0%	16.7%	17.1%	15.1%	38.1%	76.2%
no charge	10.8%	15.0%	16.4%	15.7%	42.2%	74.3%
only 4-momentum	7.0%	11.4%	14.5%	15.6%	51.5%	70.3%