graFEI: Full Event Interpretation using Graph Neural Networks at Belle II

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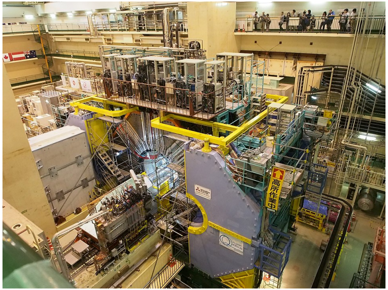
Training at HoreKa and CC-IN2P3:

Belle II

Belle II : e^+e^- collisions at SuperKEKB collider, Japan
B-factory: $\Upsilon(4S) \to B\bar{B}$

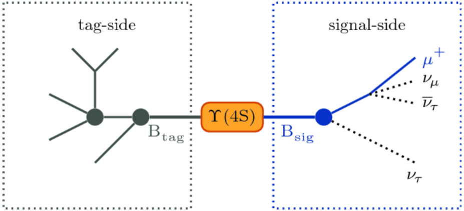
- Record instant luminosity
- Hermetic detector: reconstructs all long-lived particles
- Clean environment
  - ~ 10 tracks per event



$\to$ Allow the reconstruction of the entire collision event !

... and taking data also during COVID pandemic!

Reconstruction of the collisions



[arXiv:1807.08680]

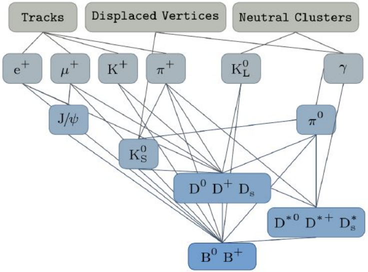
- Interested in events with neutrinos: we must reconstruct B_{tag}
- Combinatorial problem
- Thousands of possible decays

$\rightarrow$ Necessity of a powerful reconstruction algorithm

The current solution: the FEI

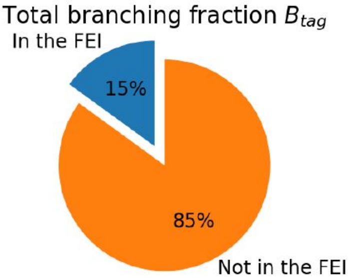
The Full Event Interpretation [arXiv:1807.08680] algorithm is the current algorithm in Belle II for event reconstruction.

- Hierarchical machine learning algorithm
- Six levels of Boosted Decision Trees
- More than 10000 decays considered



Limitations of the FEI

- 6 stages are disconnected
- Sub-decays need to be hard-coded
- Overall efficiency $\sim 1\%$



$\rightarrow$ Room for improvement !

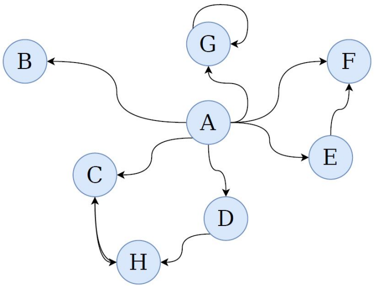
Challenges to design a solution

- Decay trees are invariant under permutation of final state particles
- The number of final state particles is not fixed
- Graphs provide a very good framework satisfying these conditions

$\rightarrow$ Use graph networks

Graph

A graph is a set of nodes, connected by edges.

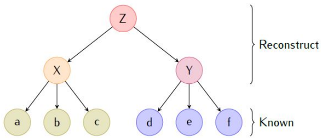


GraFEI

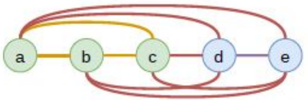
GraFEI: Replacing the FEI with a Graph Neural Network-based method

Decay trees as graphs

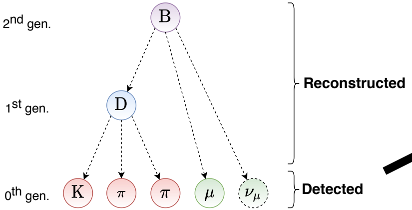
Our approach: represent the decay tree using the Lowest Common Ancestor Generation matrix (LCAG)

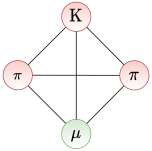


	a	b	c	d	e	f
a	0	1	1	2	2	2
b	1	0	1	2	2	2
c	1	1	0	2	2	2
d	2	2	2	0	1	1
e	2	2	2	1	0	1
f	2	2	2	1	1	0



Decay trees as graphs





Feature Matrix

E_K	E_π	E_π	E_μ
p_{xK}	$p_{x\pi}$	$p_{x\pi}$	$p_{x\mu}$
p_{yK}	$p_{y\pi}$	$p_{y\pi}$	$p_{y\mu}$
p_{zK}	$p_{z\pi}$	$p_{z\pi}$	$p_{z\mu}$

Insert GraphNN here

Lowest Common Ancestor (LCA) Matrix

	K	π	π	μ
K	0	1	1	2
π	1	0	1	2
π	1	1	0	2
μ	2	2	2	0

Adjacency Matrix

	B	D	K	π	π	μ
B	0	1	0	0	0	1
D	1	0	1	1	1	0
K	0	1	0	0	0	0
π	0	1	0	0	0	0
π	0	1	0	0	0	0
μ	1	0	0	0	0	0

I. Tsaklidis, *Demonstrating learned particle decay reconstruction using Graph Neural Networks at Belle II*, Master Thesis

Our Graph Network

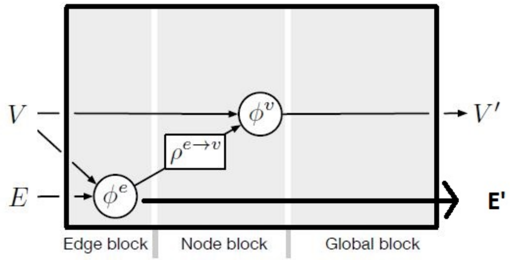


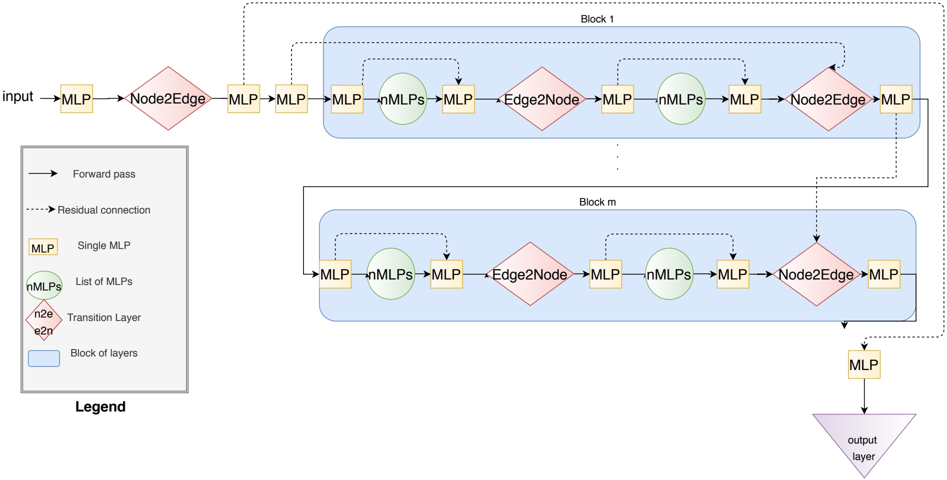
Figure 1: Graph Network block

[arXiv:1806.01261]

$$e'_{ij} = \phi^e(e_{ij}, v_i, v_j) = NN^e$$
$$\bar{e'}_i = \rho^{e\to v}(E'_i) = < e'_{ij} >$$
$$v'_i = \phi^v(v_i, \bar{e'}_i) = NN^v$$

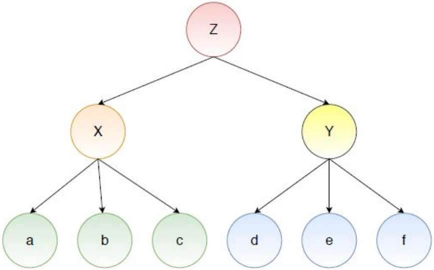
Our Graph Network

Using Neural Relational Inference [arXiv:1802.04687]

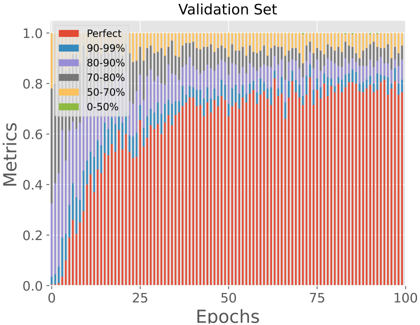


I. Tsaklidis

Proof of concept



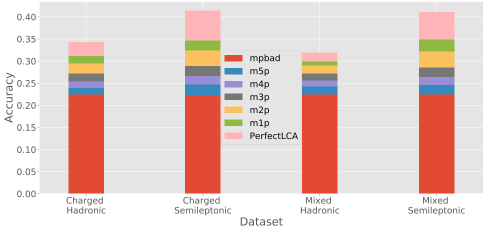
Particle	Z	X	Y	a, b, c, d, e, f
Mass (arb.units)	200	80	60	5



Test on generic Belle II MC

graFEI on 2 million simulated $B\bar{B}$ samples

- $\Upsilon(4S) \to B^0\bar{B}^0$ (mixed)
- $\Upsilon(4S) \to B^+B^-$ (charged)
- use **MC Truth** particle features of all final state particles

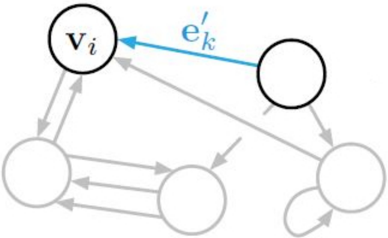


(charged hadronic) 7.8% perfectly predicted trees
(charged semileptonic) 17.2% perfectly predicted trees

Conclusion

- We aim at improving the current event reconstruction algorithm
- Encouraging early results on generic and Monte-Carlo decays
- Next step:
  - Training on Belle II simulated data
  - Fair comparison to the FEI

Backups



(a) Edge update (b) Node update

[arXiv:1806.01261]