

Introduction

- At the Belle II experiment, e^+e^- pairs are collided at the center of mass energy of the $\Upsilon(4S)$ resonance producing pairs of B mesons
- The presence of invisible particles (e.g. neutrinos) in signal decays (B_{sig}) is deduced by the energy-momentum imbalance after reconstructing the companion B meson in the event (B_{tag})
- This task is complicated by the presence of thousands of decay modes the B can decay into.

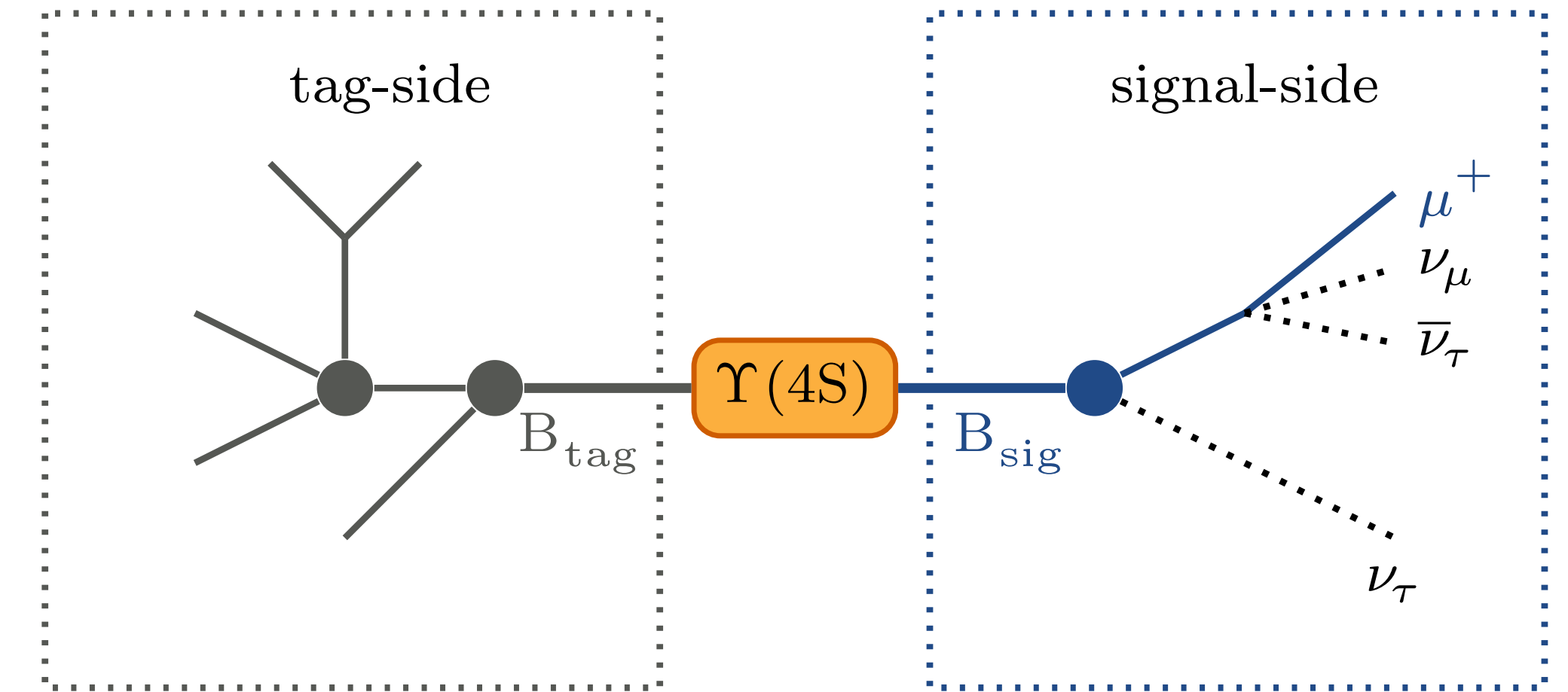


Figure 1: Schematic representation of a $\Upsilon(4S)$ decay into two B mesons.

Full Event Interpretation

B_{tag} reconstruction performed at Belle II with the **Full Event Interpretation (FEI)**[1]:

- Hierarchical approach based on Boosted Decision Trees
- About 10k B decay modes reconstructed
- Overall reconstruction efficiency of $\mathcal{O}(1\%)$
- Output of final stage interpreted as “ B probability”
- Decay modes hard-coded, about 85% B decays not considered.

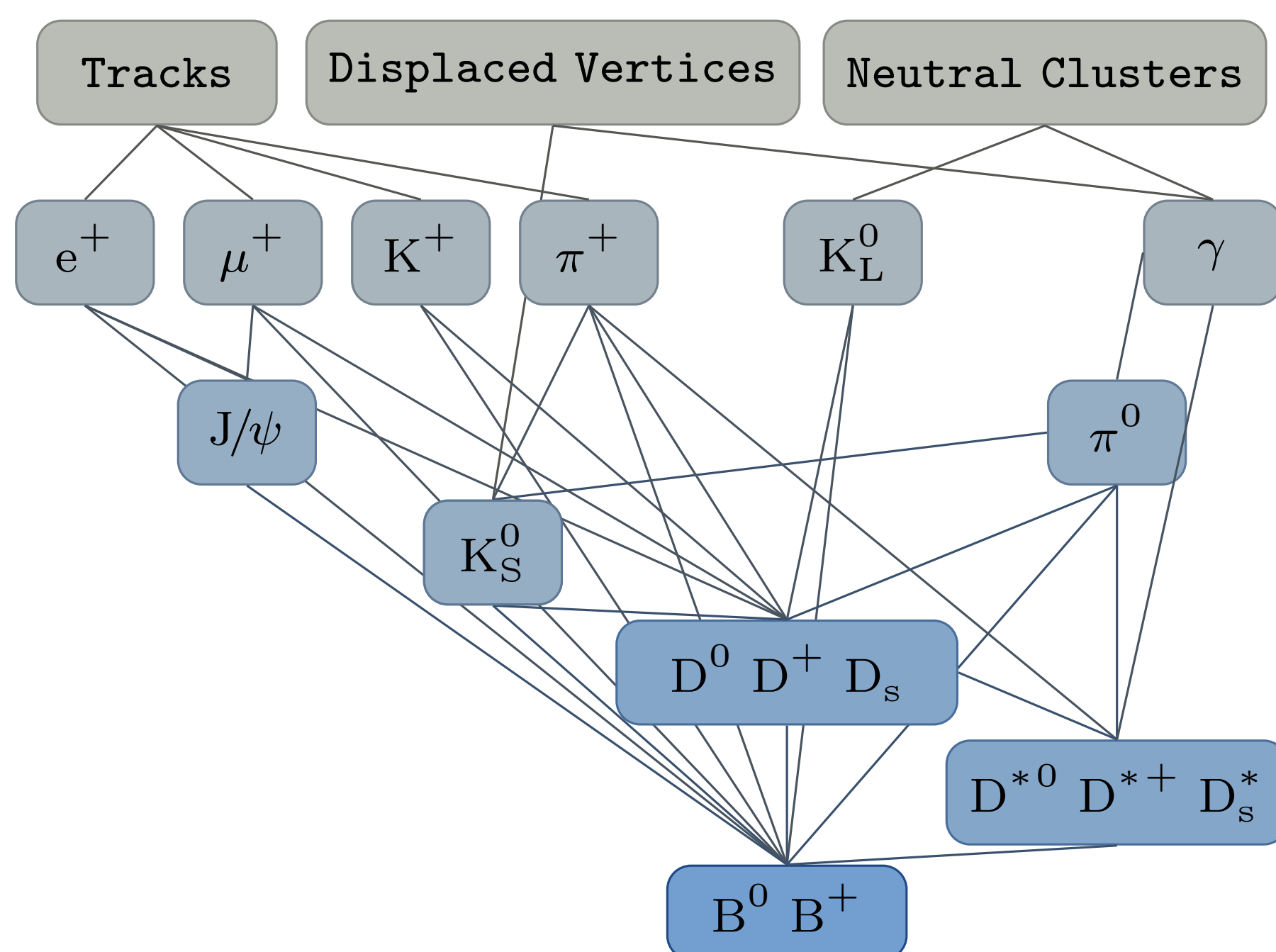


Figure 2: Schematic view of the FEI stages.

B_{tag} reconstruction with Deep Graph Neural Networks

Goal: reconstruct the **Lowest Common Ancestor (LCA)** matrix [2, 3]. It enables learning the decay structure **inclusively from the final state particles alone**.

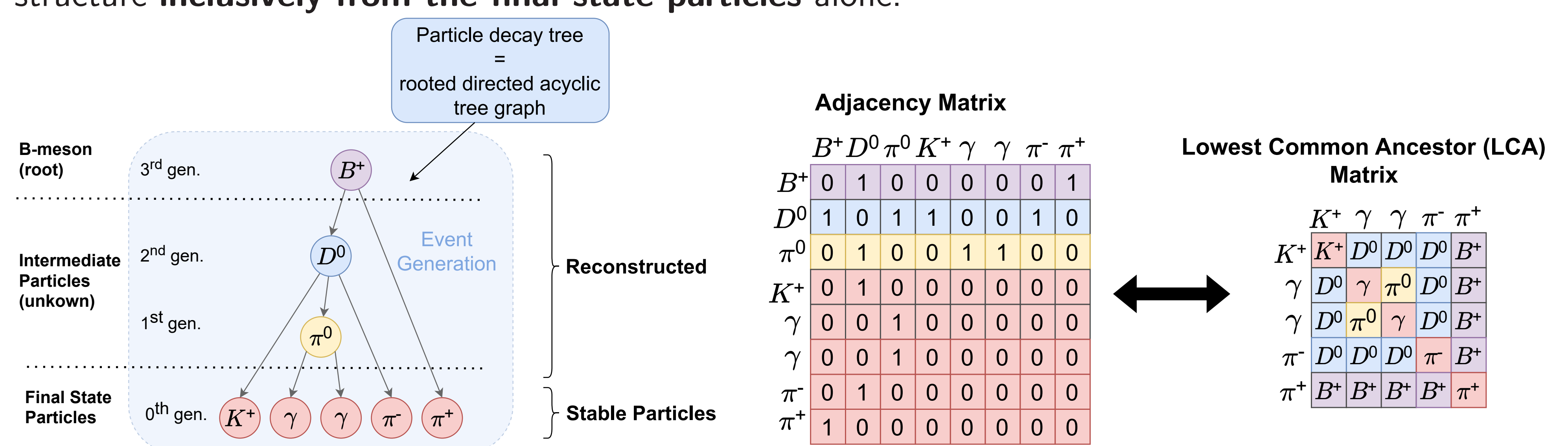


Figure 3: Example of B decay described in terms of the adjacency and LCA matrices.

Proof of concept on a phasespace dataset

The Neural Relational Inference model **correctly predicts 47.7% of LCA matrices** [4].

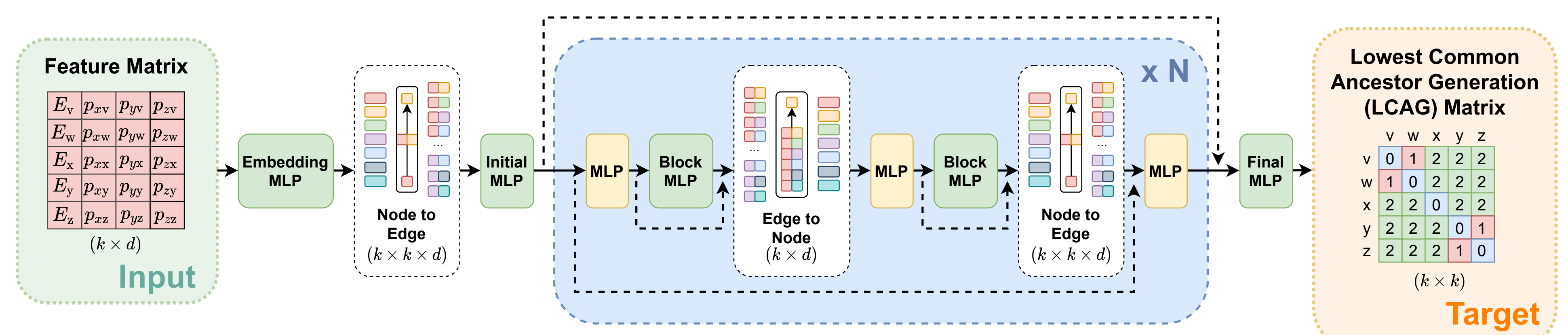


Figure 4: Schematic representation of the Neural Relational Inference model.

Application to Belle II simulation

Graph-based Full Event Interpretation (graFEI) model based on *graph network* blocks [5] and **trained on $\Upsilon(4S) \rightarrow B^0(\rightarrow \nu\bar{\nu})\bar{B}^0(\rightarrow X)$ simulated signal events**. Performances evaluated on simulated signal events and background from random combinations of tracks from B^0 decays.

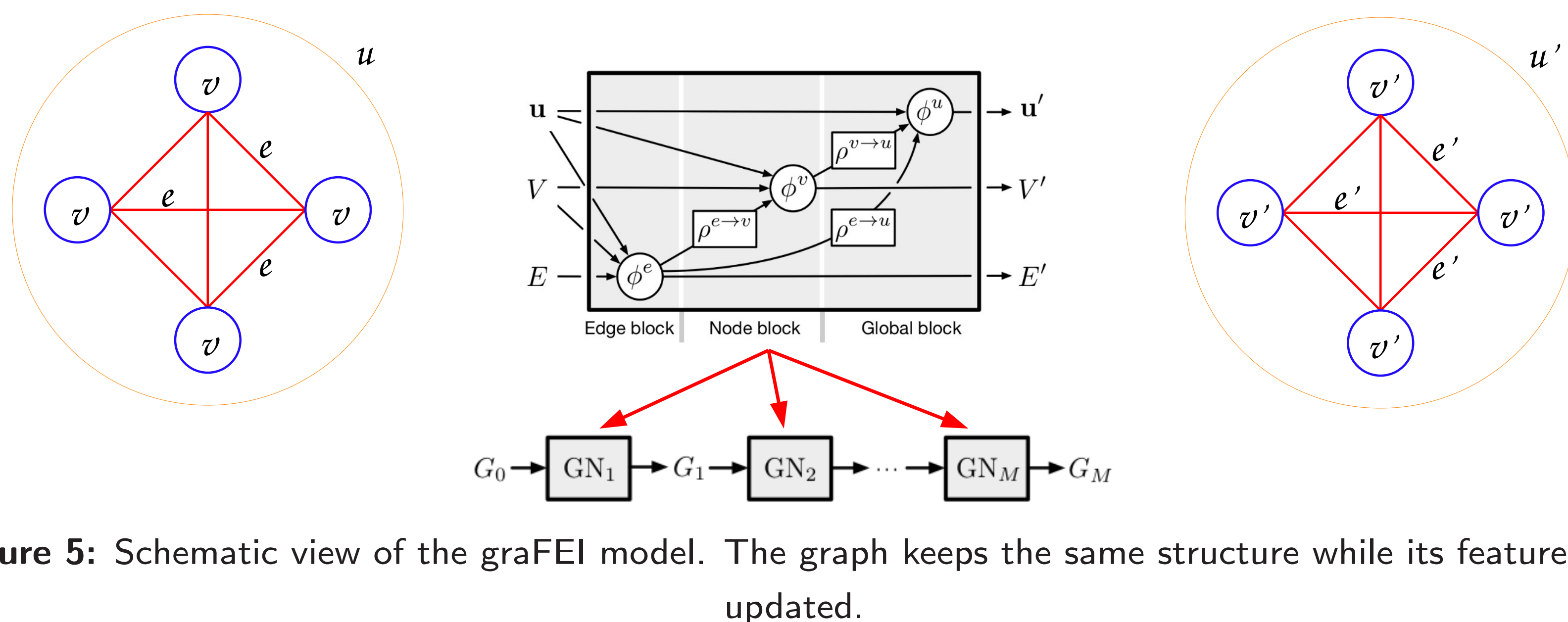


Figure 5: Schematic view of the graFEI model. The graph keeps the same structure while its features are updated.

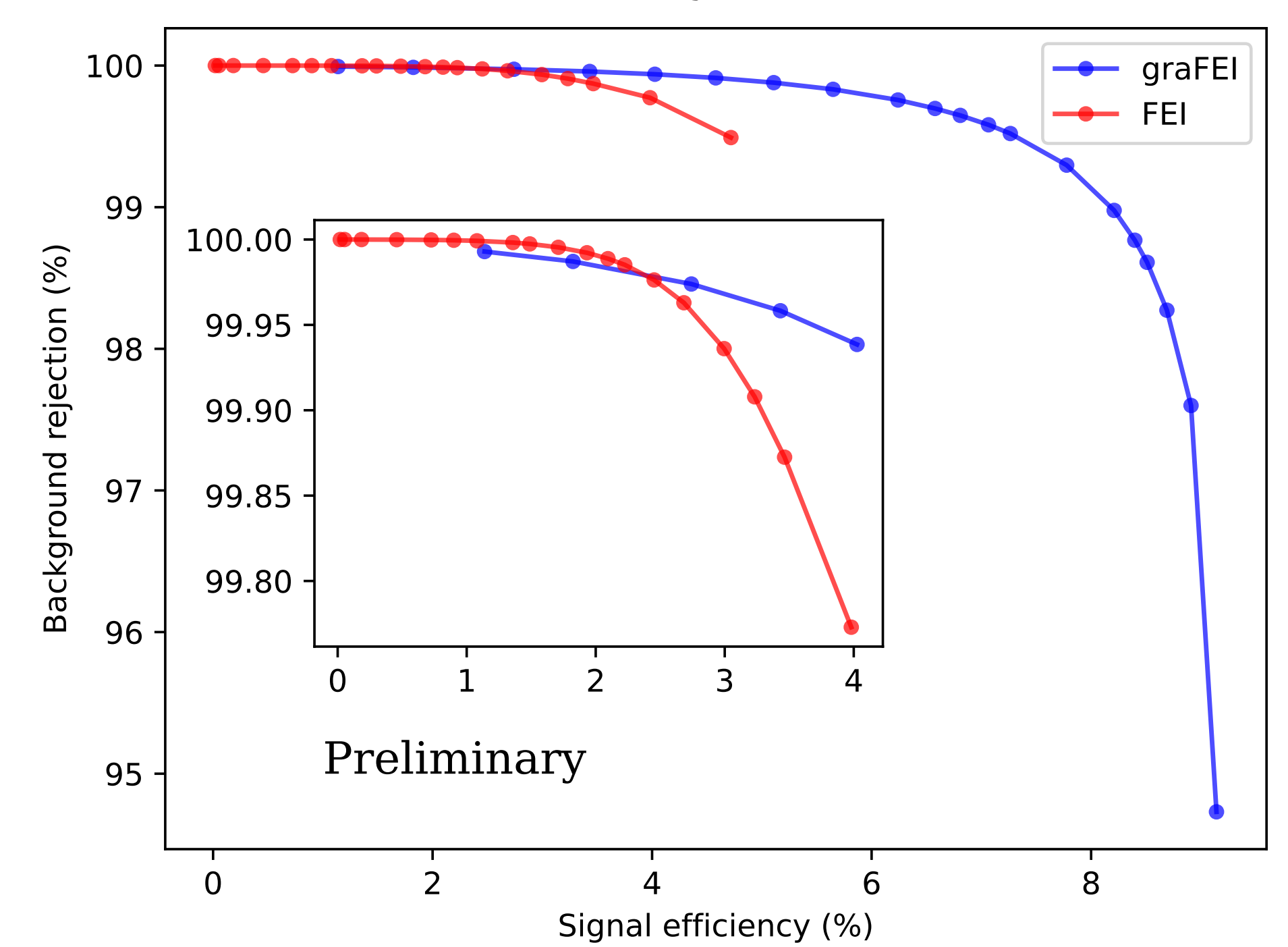


Figure 6: Signal efficiency and background rejection for FEI and graFEI.

Conclusion

- B_{tag} reconstruction currently performed with the FEI, limited to specific **hard-coded decays**
- **Reconstructing the LCA matrix using graph neural networks** allows to inclusively reconstruct B decays without any prior assumption on the nature of the decay
- With the graFEI model an **improvement of a factor ~ 2 in efficiency** is observed with respect to the FEI performances.

References

- [1] T. Keck et al. 10.1007/s41781-019-0021-8
 - [2] I. Tsaklidis et al. docs.belle2.org/record/2122
 - [3] L. Reuter et al. publish.etp.kit.edu/record/22115
 - [4] J. Kahn et al. 10.1088/2632-2153/ac8de0
 - [5] P. Battaglia et al. 10.48550/ARXIV.1806.01261
- Original template by Brian Amberg.