B Meson Flavour Tagging via Quantum Machine Learning

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The study of the decays of B mesons is a key component of modern experiments in elementary particle physics which probe heavy quark mixing and CP violation, and may lead to concrete deviations from the predictions of the Standard Model and a richer understanding of the matter-antimatter asymmetry observed in the universe [1]. B meson flavour tagging, the process of determining the quark flavour composition of B mesons created in entangled pairs at high-energy particle accelerators, is an essential component of this analysis, enabling for example the study of asymmetries in the decay rate of neutral B mesons to flavour agnostic CP eigenstates [1] and the explicit violation of time reversal symmetry at the level of fundamental interactions [2].

As a classification problem, flavour tagging is difficult, depending in general on subtle correlations between the momenta and particle types of the potentially dozens of decay products emerging from the initial particle collision. Such classification tasks fall naturally within the domain of machine learning (ML), the methods of which have over the last decade enabled incredible progress in the study of problems which require the detection of faint signals within vast quantities of data. Indeed, the problem of flavour tagging has traditionally been most readily tackled via ML, in particular via the method of fast boosted decision trees [1].

Concurrently, the recent physical realisation of quantum computers has seen significant interest in the prospects of applying quantum machine learning (QML) methods to data intensive problems in particle physics [3], driven by the expected increased capacity for pattern recognition of quantum machines. In this work we apply the methods of QML to B meson flavour tagging, investigating the performance of advanced quantum algorithms such as boosted ensembles of quantum support vector machines and quantum decision trees in an attempt to surpass the current state of the art classical methods.

[1] Abudinén, F., *et al*. B-flavor tagging at Belle II. *The European Physical Journal C*, **82**, (2022)

[2] Lees, J. P., *et al*. Observation of time-reversal violation in the B_0 meson system. *Physical review letters* **109**, 211801 (2012)

[3] Heredge, J., Hill, C., Hollenberg, L., & Sevior, M. Quantum support vector machines for continuum suppression in B meson decays. *Computing and Software for Big Science*, **5**, (2021)