Proposition de sujet de stage M2 (2025) à l'Institut de Pluridisciplinaire Hubert Curien (IPHC)

Enhancing Belle II discovery potential with a graph neural network and a new vertex detector

The Belle II experiment, located near Tokyo in Japan, is a large international particle physics experiment, aiming at discovering physics processes beyond the Standard Model of particle physics. Belle II has been operating since 2019 at the SuperKEKB collider, which targets the highest ever reached instantaneous luminosity of $6 \times 10^{35}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ in order to collect several 10s billion $e^+e^- \to b\bar{b}, c\bar{c}, \tau\overline{\tau}$ processes over the next decade.

SuperKEKB collides electrons and positrons at the relatively low energy of the $\Upsilon(4S)$, around $11\,\mathrm{GeV}$, where B mesons are produced by pairs and feature a modest Lorentz boost. Consequently, their decay cascades generate a tree of vertices distant by a few tens to a few hundreds of $\mu\mathrm{m}$. Such cascades can be reconstructed from the list of tracks observed in the detector by machine learning algorithms, without a priori hypothesis on the type of decay searched for. This full event interpretation (FEI) allows to increase the efficiency tenfold compared to the standard method, which reconstructs few specific decays. Combined with the knowledge of the presence of two B mesons in the final states, the FEI technique is the the baseline of many Belle II physics analysis.

However, machine learning algorithms have so far been used to identify to which of the two B meson decay trees the final tracks belong, but not yet to locate the decay vertex. The B decay position is nevertheless critical to some analysis, like the search of time-dependent CP-violating radiative decays conducted in the Strasbourg group. Of course the measurement precision depends on the uncertainty on the vertex position, which in turn depends not only from the quality of the track reconstruction but also on the correctness of the association of which tracks belong to which
This internship proposes to adapt the existing Graph neural network, GraFEI, developed in the group for this task. The algorithm will be trained with simulated data. Evaluating the potential improvement on the B meson vertex position estimation will be the next task.

An additional study will consist in repeating the training of the GraFEI targetting B vertex estimation with simulated data anticipating an upgrade of the Belle II vertex detector (VTX). The current technologies equipping the inner layers of the experiment are indeed expected to be replaced with monolithic CMOS pixel sensors in the coming years. Previous simulations have shown that the vertex position estimation can be improved by 10 to 30 % when reconstructed in a specific channel.
The final question to address during the internship is whether combining GraFEI with the VTX upgrade could bring substantial improvement both in efficiency and precision for the B vertex position reconstruction.

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