Three Master Theses / M2 internships Opportunities at the LPCA LHCb Group :

General Context

The **LHCb experiment**, operating at the **CERN** Large Hadron Collider (LHC), records mainly proton-proton collisions to study the properties of heavy flavour particles. After collecting data during Run 1 and Run 2, the detector underwent a major upgrade before Run 3 (started in 2022), enabling the acquisition of high-quality data at a rate increased by a factor of about 5.

The integrated luminosity at the end of Run 2 reached $9\,\text{fb}^{-1}$; the target for the Run III and IV of the LHC is to collect about $50\,\text{fb}^{-1}$ by 2033. The main physics goals of LHCb are the **precision studies of rare decays and** CP **violation phenomena** in the heavy flavour sector (b, c, and τ).

Scientific Motivation

Quark flavour-changing transitions are described in the **Standard Model (SM)** by the **Cabibbo–Kobayashi–Maskawa (CKM) matrix**, which relates quark mass eigenstates to electroweak eigenstates. The existence of a non-vanishing complex phase in this matrix provides the only source of CP violation within the SM. Most of the experimental knowledge about this phenomenon arises from observables related to b-hadron decays and mixing processes.

The **Kobayashi–Maskawa paradigm**, established by the BaBar and Belle B-factory experiments, accounts for the CP violation observed at the electroweak scale. However, cosmological observations strongly suggest that **additional sources of** CP **violation must exist**. The LHCb experiment aims to further improve the precision on CKM parameters and to constrain—or possibly reveal—new sources of CP violation.

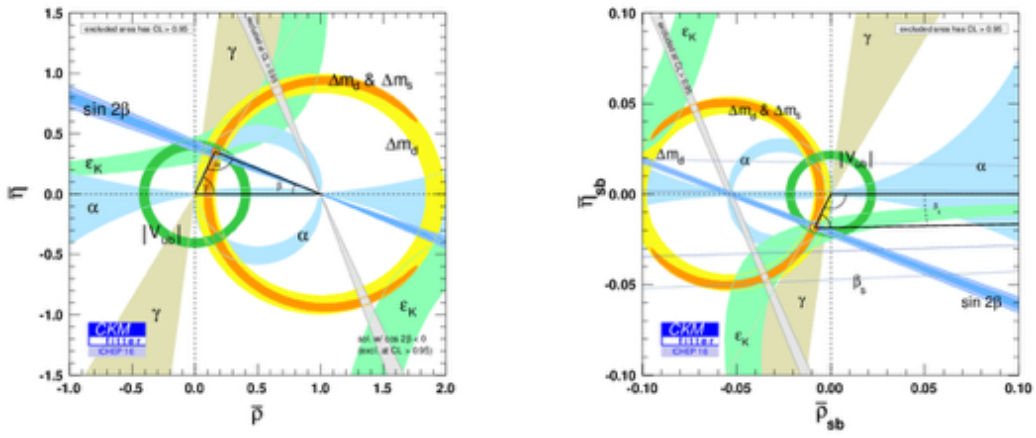

FIGURE 1 – Unitarity triangles associated with the CKM angles β (left) and β_s (right).

Proposed Master Thesis Topics

The proposed master thesis / internship subjects are part of the program dedicated to measuring the weak phases governing the B_d^0 and B_s^0 mixing phenomena, identified in the SM as the CKM angles β and β_s (see Fig. 1). Depending on the candidate's interests, the thesis will focus on one of the following themes :

1. Dalitz-plot analyses of charmless three-body decays

— Study of neutral B_d^0 and B_s^0 meson decays including a K_S^0 or a neutral pion in the final state ;
— Determination of decay amplitudes using quantum interference models ;
— Final goal (beyond the scope of this internship / thesis) : determination of *CP* violation parameters and CKM angles β and β_s.

2. Improving ***Flavour Tagging*** performance using Deep Learning

— *Flavour Tagging* (FT) is a key ingredient in most of the *CP* mixing-induced asymmetry analyses, as it determines the initial flavour of neutral B mesons ;
— The project will focus on developing and testing **Deep Learning methods** to enhance FT performance ;
— Final goal (beyond the scope of the this internship / thesis) : improved precision across a wide range of measurements within the LHCb collaboration.

3. Vertex reconstruction and combinatorial optimisation in high-luminosity conditions

— Study of primary and secondary vertex reconstruction performance in an environment with multiple interactions per bunch crossing ;
— Development and evaluation of **Deep Learning approaches** to address increasing combinatorial complexity in traditional algorithms ;
— Final goal : ensure reconstruction quality equal or superior to that achieved during Run 2, despite the higher luminosity environment.

Supervision and Work Environment

The work will be supervised within the LHCb group, in close collaboration with the PhDs, the post-docs team, and the senior researchers. The first period of the thesis / internship will involve hands-on tutorial and common work on the current Flavour Tagging algorithms by testing and providing some relevant calibration for the physics modes used in the group. Another area of joint effort at beginning of the internship will concern developments on the homemade amplitude fitter tool CRAFT useful to the Dalitz-plot analyses. The progresses of these concurrent works will be shared and discussed in weekly meetings.

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