V_{us} BFFs (branching-fraction form factor synergy) - Study of electroweak form factors and determination of V_{us}

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1 Research objectives

Semileptonic decays involves a transition between two hadrons with the emission of a W boson that decays into a charged lepton – antineutrino pair. These are directly related to the CKM matrix, as their decay rates are proportional to CKM matrix elements squared like $|V_{us}|^2$ for strange quark transitions. Since the semileptonic decays are less affected by strong interaction uncertainties, they offer a clean way to extract CKM matrix elements with high precision. If the CKM matrix is the complete description of flavour-changing quark transitions, the matrix has to be unitary.

Most of our knowledge about the CKM matrix elements, beyond the well-measured $|V_{ud}|$, comes from meson decay studies. Initial hints of deviations from weak universality have emerged from measurements of $|V_{us}|$ and $|V_{cs}|$ [1, 2].

Baryon semileptonic decays provide a complementary avenue for testing the CKM matrix. Semileptonic decays, in which a baryon decays into a lighter baryon and a charged lepton–neutrino pair with invariant mass squared q^2, are particularly useful for extracting precise CKM matrix element values. In particular, semileptonic decays of strange baryons, *hyperons*, provide a complementary path to determine $|V_{us}|$ [3, 4]. differential decay widths for the transitions within the $1/2^+$ baryon octet, considered in this project, are proportional to $|V_{us}|^2$ and the hyperon structure is parameterised in terms of six q^2-dependent form factors - vector (f_1, f_2, f_3) and axial vector (g_1, g_2, g_3). However, only three, f_1, f_2 and g_1, are relevant and contribute to the electronic decay widths. The f_1 and f_2 are analogous to the electromagnetic Dirac and Pauli form factors.

A prerequisite to extract $|V_{us}|$, in addition to the measurement of branching fractions for the octet hyperon decays, comes from knowledge of the form factors. Physicists can experimentally determine the relative form factors, such as g_1/f_1 or f_2/f_1, from the decay asymmetries and lepton angular and invariant mass distributions. At present, these measurements limit the precision of the $|V_{us}|$ determination from baryons, $|V_{us}| = 0.2250 \pm 0.0027$ [4, 5], presently contributing 80% of the overall uncertainty. These form factors are interesting in their own right, as they encode information on hyperon structure. They can be calculated from first principles using lattice QCD formulation or derived using other theory approaches like functional methods (Dyson-Schwinger), quark models, or dispersion theories. The most effective approach to determine $|V_{us}|$ is to compare experiments with lattice QCD and other predictions for the relative form factors to have confidence in the absolute normalisation that must be obtained reliably from QCD. This project aims to prepare comprehensive analysis methods and theoretical calculations to extract these form factors and, ultimately, a competitive V_{us} extraction. For CBM, it will contain feasibility studies of the reconstruction of exclusive final states in *pp* collisions with hyperon $(\Xi^-, \Lambda, \Sigma^\pm)$ semileptonic decays (electron and muon) and extraction of the relative form factors in function of q^2. From LHCb, the semileptonic muonic decay channels will be analyzed using data from the ongoing Run 3 data campaign.

Funding would be used for experimental feasibility studies at CBM and common workshops bringing together the experimental and theory communities.

2 Connection to Transnational Access infrastructures (TAs)

- GSI/FAIR : CBM experiment
- CERN/LHCb
- ECT* : Workshops related to the project

3 Estimated budget request

ca 400 kEUR: 200 kEUR for feasibility studies CBM and 200 kEUR for meetings

PhD (partial contribution): (CBM feasibility studies, LHCb data analysis) and meetings

4 Participating and partner institutions

In no particular order

- **LHCb experiment** (CERN).
  Participating Institutes: EPFL, NCBJ Warsaw, Universidade da Coruña, Uppsala University
- **CBM Collaboration** (FAIR). Collaboration board has expressed commitment to the project
- **Lattice QCD**
  Participating Institute: University of Cyprus
- **Theory and Phenomenology**
  Participating institutes: Lund University, NCBJ Warsaw, Uppsala University, University of Giessen, University of Graz, LIP/ IST University of Lisboa

References

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[3] H. Leutwyler and M. Roos. "Determination of the Elements V(us) and V(ud) of the Kobayashi-Maskawa Matrix". In: *Z. Phys. C* 25 (1984), p. 91. DOI: 10.1007/BF01571961.

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