Seach for $B \to \nu\bar{\nu}$ decays at the Belle II experiment

Thesis at University of Strabourg under the supervision of
Pr. Isabelle Ripp-Baudot and **Pr. Giulio Dujany**

by
Corentin Santos

University of Strasbourg
Date

Abstract

This is a summary.

Contents

1

Theoretical context

The Standard Model (SM) of particle physics is a theoretical framework that describes the electromagnetic, weak and strong nuclear interactions between elementary particles. Based on the principles of Quantum Field Theory (QFT), it has been tested extensively and has been able to describe the observations of particle physics experiments with great accuracy. However, there are several phenomena that the SM is not able to explain, such as the existence of Dark Matter (DM) or the matter-antimatter asymmetry in the universe. For reasons discussed later on, many tensions with the SM have been previously observed when quark's flavour transitions occur, such as in the $b \to sl^+l^-$, $b \to c\tau\nu$ or $b \to s\nu\bar{\nu}$ transitions. We will study the last one in this thesis, via the prism of the $B \to K\nu\bar{\nu}$ decay. In this chapter, we will first introduce the theoretical framework behind the SM and its limitations (1.1), which will lead us to the formulation of the SM as an Effective Field Theory (EFT) (1.2) and the study of the $B \to K\nu\bar{\nu}$ decay (1.3). We will then mention New Physics (NP) models which could intervene in the $B \to K\nu\bar{\nu}$ decay and the experimental constraints on these models (1.4). Finally, we will present the state of the art in the measurement of the $B \to K\nu\bar{\nu}$ decay (1.5).

1.1 The Standard Model of particle physics

The SM provides mathematical tools to describe the interactions between elementary particles, which can be *fermions*, with half-odd spin, or *bosons*, with integer spin. The elementary bosons, or *gauge bosons*, act as mediators of the fundamental interactions: *electromagnetic*, *weak* and *strong* interactions. The elementary fermions are, in this theory, 12 particles (and 12 anti-particles) forming multiplets of the groups $\mathrm{SU}(3)_C$, $\mathrm{SU}(2)_L$ and $\mathrm{U}(1)_Y$.

The $SU(2)_L \otimes U(1)_Y$ gauge group describes the electroweak interaction, mediated respectively by the $\left(W^i\right)_{i\in[\![1,3]\!]}$ and B bosons, acting on the *weak isospin* T and the *weak hypercharge* Y.

The $\mathrm{SU}(3)_C$ gauge group describes the strong interaction, and act only on particles with a *colour charge* $C \in \{R, G, B, \bar{R}, \bar{G}, \bar{B}\}$. This group being of dimension 8, it has 8 gauge bosons, called *gluons* $(g_i)_{i\in[\![0,8]\!]}$. Elementary fermions can then be separated in two categories:

- *Quarks*, with a colour charge, which are grouped in three generations, each containing two quarks with electric charge $Q = \frac{2}{3}$ and one with $Q = -\frac{1}{3}$, as follows:

$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \quad \begin{pmatrix} t \\ b \end{pmatrix}$$

  and their anti-particle equivalents. As they interact with the strong nuclear force, quarks are never observed in isolation, but always in bound states called hadrons (except for the top quark because of its mass), since free particles must always have a "null" colour charge. Particles composed of two quarks are called mesons, and those composed of three quarks are called baryons.

- *Leptons*, without a colour charge, which are also grouped in three generations, each containing a charged lepton and a neutrino, as follows:

$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \quad \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}$$

and their anti-particle equivalents.

All of the fermions interact weakly, and charged fermions also interact electromagnetically. From the way they act under $SU(2)_L$, one can write the fermions as *weak-isospin doublets*

$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix}_L \quad \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}_L \quad \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}_L \quad \begin{pmatrix} u' \\ d' \end{pmatrix}_L \quad \begin{pmatrix} c' \\ s' \end{pmatrix}_L \quad \begin{pmatrix} t' \\ b' \end{pmatrix}_L$$

and *weak-isospin singlets*

$$e_R^- \quad \mu_R^- \quad \tau_R^- \quad u_R' \quad c_R' \quad t_R' \quad d_R' \quad s_R' \quad b_R'$$

with the L and R subscripts indicating the chirality of the particles, left-handed or right-handed, respectively. The right-handed neutrinos are not included in the SM.

1.2 An Effective Field Theory approach to the Standard Model

1.3 The $B \to K\nu\bar{\nu}$ decay in the Standard Model

1.4 New Physics models in the $B \to K\nu\bar{\nu}$ decay

1.5 State of the art

PATATA

[1]

2

Conclusion

This is a conclusion.

List of acronyms

DM Dark Matter. 5

EFT Effective Field Theory. 5

NP New Physics. 5

QFT Quantum Field Theory. 5

SM Standard Model. 5, 6, 7

Bibliography

[1] A N Kolmogorov. *Foundations of the theory of probability.* Chelsea Publishing Company, New York, NY, USA, 1956. (cited on page 7)