Poglavje 1

Povzetek doktorskega dela

1.1 Uvod

Fizika delcev je eden od stebrov fizike, z močnimi koreninami, ki segajo vse do zaetka 20. stoletja. Natančni eksperimenti in preverljiva teorija so pokazali, da vesolje sestoji iz osnovnih delcev in nosilcev interakcij. Osnovne delce delimo na kvarke (u, d, s, c, b, t) in leptone, ki so nadaljnje razdeljeni na nabite leptone (e, μ, τ) in pa nevtrine (ν_e, ν_μ, ν_τ). Nosilci tirih osnovnih interakcij so fotoni (γ) za elektromagnetno, gluoni (g) za mono in nabiti- ($W^\pm$) ter nevtralni (Z^0) bozoni za ibko interakcijo. Vse delci imajo maso, ki jim jo doloa Higgsov bozon (H). Vse delce ter interakcije med njimi opisuje Standardni model, ki je osrednja teorije fizike visokih energij. Kvarke lahko zdruujemo v kombinacije oblike $q_1q_2q_3$ (hadroni) ali pa $q_1\bar{q}_2$ (mezoni), med katere sodijo tudi protoni in nevtroni, ki jih opazimo v naravi. Poleg omenjenih dolgo-iveih delcev pa obstajajo tudi teji, bolj nestabilni delci, ki preko zgoraj natetih interakcij razpadejo v laje, stabilneje. Raziskovanje taknih procesov s pomojo pospeevalnikov in trkalnikov nam omogoa spoznati zakone vesolja vse od danes pa do njegovega zaetka.

Osrednji del doktorske disertacije predstavljajo mezoni B, delci, ki so sestavljeni iz tekega kvarka b in enega od lahkih kvarkov u ali d. Ena od bolj presenetljivih lastnosti vesolja je kritev simetrije CP, t.j. kombinacije simetrij konjugacije naboje (C) in prostorske inverzije (P). Simetrija CP nakazuje, da so fizikalni procesi delcev in zrcalni procesi antidelcev enaki, kar pa danes vemo, da ne dri v celoti in poznamo procese, ki to simetrijo krijo. Kritev simetrije CP je tesno povezana s ibko interakcijo, to pa predstavlja nao motivacijo za tudijo mezonov B, saj ibki razpadi predstavljajo veji del razpadov mezonov B.

Edinstvena lastnost ibke interakcije je, da lahko spreminja tip oziroma t.i. okus kvarkov, medtem ko ga ostale interakcije ohranjajo. Takni procesi so opisani s prehodno matriko

CKM (Cabibbo-Kobayashi-Maskawa) [1, 2]

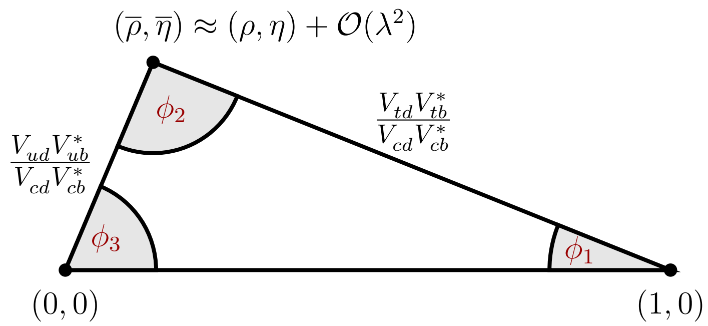
$$V_{CKM} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}. \tag{1.1}$$

Unitarnost matrike CKM nam omogoa, da iz nje izluimo matematine identitete, od katerih je ena od pomembnejih

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0, \tag{1.2}$$

ki je poznana pod imenom unitarni trikotnik, saj predstavlja zakljuen vektor treh tok v kompleksni ravnini, ki ga prikazuje Slika 1.1.

It can be represented by a triangle in the complex plane, called the unitarity triangle, shown in Figure **??**. The sides and the angles of the unitarity triangle are closely connected to the free parameters of the CKM matrix. It is important to mention that all experimental measurements depend only on these four parameters, so it is possible to determine them by measuring the angles and sides of the unitarity triangle. This way the unitarity triangle offers us a unique way to test the consistency of the SM. The ultimate goal is to then join all such measurements and overconstrain the unitarity triangle to check if all the sides meet. By improving such measurements one can check whether the SM is consistent, or if there are some contributing physics processes that we do not yet understand. Such processes are commonly referred to as "new physics"(NP). The measurements of the sides and angles of the triangle are done by using different decays of which a large portion are B meson decays. Here lies another motivation for using B mesons in the analysis.



Slika 1.1: The unitarity triangle with λ, η, ρ and A (not shown) as free parameters of the CKM matrix.

In this analysis we focus on the V_{ub} CKM matrix element, which corresponds to $b \to u$ quark transitions. It has the smallest absolute value of all the CKM matrix elements and the largest error, so it offers the most room for improvement. Such quark transitions are present in charmless semi-leptonic B meson decays of the form

$$B^+ \to X_u^0 \ell^+ \nu_\ell, \tag{1.3}$$

where X_u^0 represents a charmless hadron with a u quark and ℓ is one of the charged leptons e, μ or τ. Measuring the decay rate of the B meson in such decays paves the way for the CKM matrix element determination. Decay rates are directly connected to the V_{ub} element as

$$\mathrm{d}\Gamma \propto G_F^2 |V_{ub}|^2 |L^\mu \langle X_u | \bar{u} \gamma_u \frac{1}{2}(1-\gamma_5) b | B \rangle|^2, \tag{1.4}$$

where Γ is the decay width, G_F is the Fermi coupling constant, L^μ is the leptonic current and the expression in the Dirac brackets is the hadronic current. The factor $|V_{ub}|^2$ represents the probability for the $b \to u$ quark transition. Measurement of the V_{ub} CKM matrix element can be performed in two possible ways. With the exclusive or the inclusive method, which are described below. Both methods require different experimental and theoretical techniques, so they provide largely independent determinations of $|V_{ub}|$. Currently both methods also have comparable accuracies.

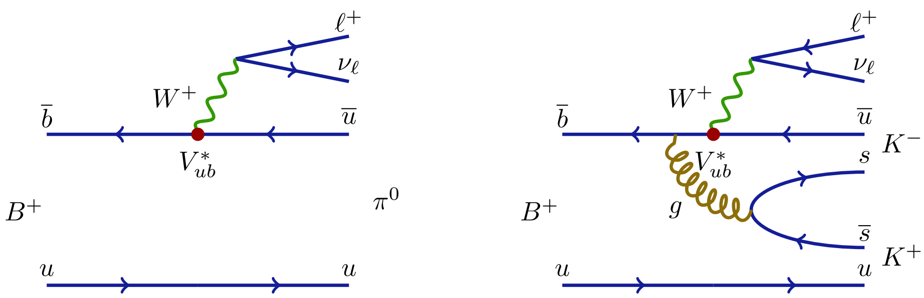
In the exclusive method one studies the decays of B mesons to a specific charmless hadronic final state, such as $B \to \pi \ell \nu$. Clean determination of the V_{ub} is possible due to precise experimental measurement along with reliable theoretical calculations. However, theoretical calculations are more challenging for decays to a specific final state, since hadronization of quarks has to be taken into account. There are also two main experimental challenges in this method. One has to reduce the abundant background from $B \to X_c \ell \nu$ processes, since the $b \to c$ quark transition is much more common. The second experimental challenge is to separate the B meson decay with the specific charmless hadronic final state from other $B \to X_u \ell \nu$ decays, since it roughly populates the same regions of the phase-space as the signal decay.

In the inclusive method one studies the decays of B mesons to any charmless hadronic final state $B \to X_u \ell \nu$. In this case, the total decay rate for $b \to u \ell \nu$ can be calculated accurately, since hadronization does not have to be taken into account. The greater challenge with this method is again the experimental measurement of the total decay rate due to the $B \to X_c \ell \nu$ background. Experimental sensitivity to V_{ub} is highest where $B \to X_c \ell \nu$ decays are less dominant. Theory and experiment have to compromise and limit the V_{ub} determination to a region where the signal-to-background ratio is good. Theory takes this into account by reliably calculating the partial decay rate $\Delta\Gamma$, which is more challenging than the total decay rate. One possible and often used approach to reduce $b \to c$ background is to reject all events with K particles, or kaons, present in the final particle selection. The procedure is called a K-veto. Kaons consist of an s quark, which is mainly produced in $c \to s$ transitions. This means that if a kaon is found in the event, it is very likely that it originates from a particle with a c quark, indicating the $b \to c$ process.

If V_{ub} is determined with both these methods, the values can be compared. It turns out that consistency between these two results is only marginal, where the difference is at a level of 3σ. The current world averages [3] of the exclusive (from $B^0 \to \pi^- \ell^+ \nu$) and inclusive (GGOU collab. [4]) are

$$|V_{ub}|_{\text{excl.}} = (3.65 \pm 0.09 \pm 0.11) \times 10^{-3}, \tag{1.5}$$
$$|V_{ub}|^{\text{GGOU}}_{\text{incl.}} = \left(4.52 \pm 0.15 \;^{+0.11}_{-0.14}\right) \times 10^{-3}, \tag{1.6}$$

where the first and the second errors are the experimental and the theoretical error, respectively. We see that inclusive measurements prefer higher values than exclusive ones. This is known as the V_{ub} puzzle. It is necessary to make further research as to why this difference occurs. The reason could be an unknown experimental or theoretical error, or it is even possible that some NP contributions occur. This analysis will focus on a possible reason that could be hidden in the selection mentioned before. By performing a K-veto, one discards all events with kaons in the final state in order to suppress $b \to c$ contributions. In this analysis we focus on the charged $B \to KK\ell\nu$ decay, which is very similar to the $B \to \pi\ell\nu$, except for a production of an $s\bar{s}$ quark pair, which then combines with final state quarks to form kaons, as shown in Figure 1.2. In this case, we have kaons in the final state where the B meson decayed via a $b \to u$ process. Such decays were discarded in previous V_{ub} determinations with the inclusive method, but in principle they contribute to the result and should be taken into account. The results of this analysis should help us make a step closer to solving the V_{ub} puzzle.



Slika 1.2: Feynman diagrams for the $B^+ \to \pi^0\ell^+\nu_\ell$ decay (left) and the $B^+ \to K^-K^+\ell^+\nu_\ell$ decay (right).

Specifically, we will be focusing on decays of the charged B mesons of the form $B^+ \to K^+K^-\ell^+\nu$, since it includes two charged kaons, as opposed to the case of the neutral B meson decay. The reason for this is a simpler decay chain and a higher reconstruction efficiency. All further occurrences of $B \to KK\ell\nu$ automatically imply decays of the form $B^+ \to K^+K^-\ell^+\nu$ and its charge conjugated counterpart.

1.2 Experimentalna postavitev

1.2.1 Trkalnik KEKB

1.2.2 Detektor Belle

1.3 Postopek analize

1.4 Sistematske negotovosti

1.5 Končni rezultat