

Chapter 1

Introduction

In particle physics we are concerned about small objects and their interactions. Their dynamics are currently best described by the Standard Model (SM).

The SM contains two groups of fermionic, Spin $1/2$ particles. The former group, the Leptons consist of: the electron (e), the muon (μ), the tau (τ) and their corresponding neutrinos ν_e , ν_μ and ν_τ . The latter group, the Quarks contain: u , d (up and down, the so called light quarks), s (strange), c (charm), b (beauty or beauty) and t (top or truth). The SM furthermore differentiates between three fundamental forces (and its carriers): the electromagnetic (γ photon), weak (Z - or W -Boson) and strong (g gluon) interactions. The before mentioned Leptons solely interact through the electromagnetic and the weak force (also referred to as electroweak interaction), whereas the quarks additionally interact through the strong force.

The strong force is also referred to as Quantumchromodynamics (QCD). As the name suggests¹ the force is characterized by the color charge. Every quark has next to its type one of the three colors blue, red or green. The color force is mediated through eight gluons, which each being bi-colored², interact with quarks and each other. The strength of the strong force is given by the coupling constant α_s . The coupling constants are a function of energy E and $\alpha_s(E)$ increases with energy³. This is exclusive for QCD and leads to *asymptotic freedom* and *confinement*. The former phenomenon describes the decreasing strong force between quarks and gluons, which become asymptotically free at large energies. The latter expresses the fact, that no isolated quark has been found until today. Quarks appear confined as *Hadrons*, the so called *Mesons*⁴ and *Baryons*⁵. As we measure *Hadrons* in our experiments but calculate with quarks within our theoretical QCD model we have to assume *Quark-Hadron Duality*, which states that QCD is still valid for Hadrons for energies suffi-

¹Chromo is the greek word for color.

²Each gluon carries a color and an anti-color.

³In contrast to the electromagnetic force, where $\alpha(E)$ decreases!

⁴Composite of a quark and an anti-quark.

⁵Composite of three quarks or three anti-quarks.

Flavour	Mass	comment
u	$2.2^{+0.5}_{-0.4}$ MeV	$\overline{\text{MS}}$
d	$4.7^{+0.5}_{-0.3}$ MeV	
s	95^{+9}_{-3} MeV	
c	$1.275^{+0.025}_{-0.035}$ GeV	
b	$4.18^{+0.04}_{-0.03}$ GeV	
t	173.0(40) GeV	

Table 1.1: List of Quarks and their masses[PDG2018].

cently heigh energies. There exist *Duality Violations* (DV), which will be investigated within this work.

1.1 τ -Decays

1.2 Quantumchromodynamics

QCD describes the strong interaction. Strong interactions occur between *quarks* and are transmitted through *gluons*. A list of quarks can be found in 1.2.

The QCD Lagrange density is similar to that of QED[Jamin2006],

$$\mathcal{L}_{\text{QCD}}(x) = -\frac{1}{4}G_{\mu\nu}^a(x)G^{\mu\nu a}(x) + \sum_A \left[\frac{i}{2}\bar{q}^A(x)\gamma^\mu \overleftrightarrow{D}_\mu q^A(x) - m_A \bar{q}^A(x)q^A(x) \right]. \quad (1.1)$$

$$G_{\mu\nu}^a(x) \equiv \partial_\mu B_\nu^a(x) - \partial_\nu^a(x) + gf^{abc}B_\mu^b(x)B_\nu^c(x) \quad (1.2)$$