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Bachelor Thesis in Physics
submitted by

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The comparison of the single QC and the ladder QC of silicon Pixel Sensors for the Mu3e Vertex Detector

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Part I

Introduction

1 Introduction

This is the introduction to my bacheolor thesis.

2 Physical Background and Motivation

2.1 The Standard Model of Particle Physics

Here I can write something about the standard model, its particles and interactions.

- Summarizes current understanding of particle physics
- Describes fundamental particles and their interactions (fundamental forces)
- Consists of fermions and bosons (fermions: half-integer spins; bosons: integer spins)
- Three generations
- First generation: stable particles (up, down, electron, electron neutrino)
- Second and third generation: heavier, unstable particles
- Gauge bosons: force carriers
- Photon: carries electromagnetic force; gluon: carries strong force; W and Z bosons: carry weak force
- Electromagnetic and weak force \rightarrow electroweak force
- Higgs boson: gives mass to particles via the Higgs mechanism
- Gravity is not included in the Standard Model

The Standard Model of Particle Physics summarizes our current understanding of the fundamental particles and their interactions. It describes the particles that make up matter and the forces through which they interact.

As can be seen in Figure 1 the particles described in the standard model are divided into fermions with half integer spins and bosons with integer spins. Furthermore the Standard Model consists of three generations. The particles described in the first generation (up, down, electron and electron neutrino) are stable and make up the ordinary matter. The particles in the other generations increase in mass and are unstable. They are produced in high-energy processes such as cosmic rays or particle accelerators.

The twelve fermions (up, down, electron, electron neutrino, charm, strange, muon, muon neutrino, top, bottom, tau, tau neutrino) are grouped into Quarks and Leptons. Quarks carry a charge of $+\frac{2}{3}e$ or $-\frac{1}{3}e$ as well as a colour charge. This means they interact with the strong and weak force and also with the electromagnetic force. Leptons on the other hand carry an electric charge of $-e$ or 0 and no colour charge. Therefore they only interact with the weak and electromagnetic force. In each generation there are two leptons, one carrying a charge and a Neutrino which is considered massless in the Standard Model. Until the discovery of neutrino oscillations it was believed that during decays the lepton flavour is conserved. According to this each generation of Leptons has its own Lepton flavour.

The interactions between these particles are mediated by the gauge bosons. The photon γ carries the electromagnetic force. The weak force is mediated by the W^\pm and the Z boson. The W^\pm bosons carry a charge of $\pm e$ and have a mass of $80.4\text{GeV}/c^2$ while the Z boson is electrically neutral and has a mass of $91.3\text{GeV}/c^2$. The weak and the electromagnetic force can be unified into the electroweak force. The strong force is mediated by the gluon g which itself carries a

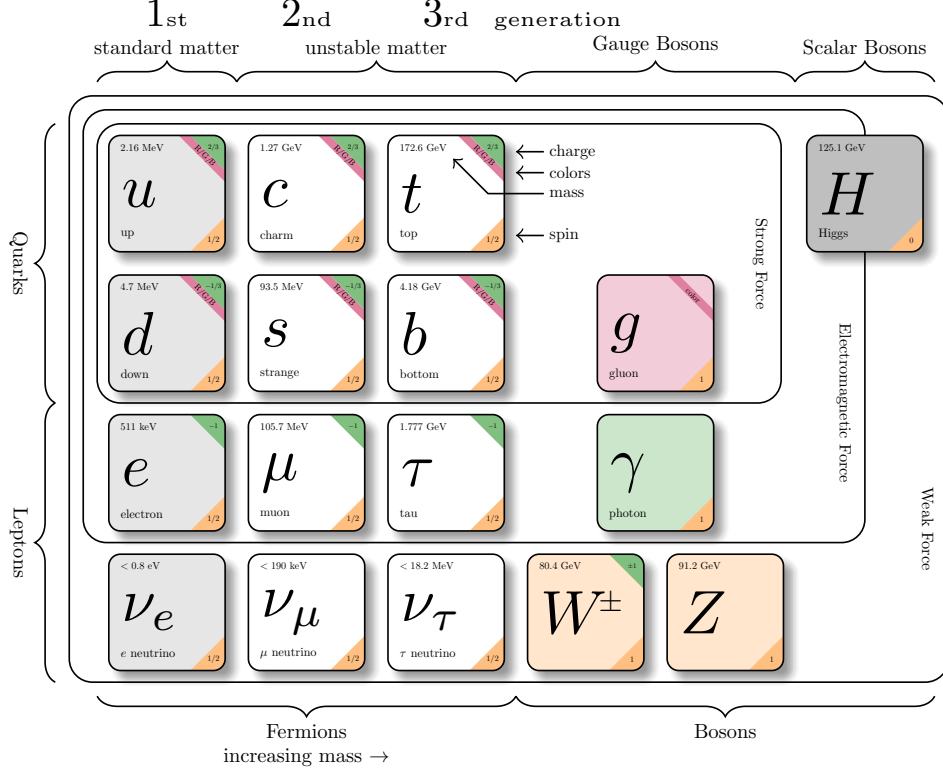


Figure 1: Visualisation of The Standard Model of Particle Physics taken from[2] and modified with values taken from[1]

colour charge. This means that gluons can interact with themselves.

Thus all forces except for gravity are included in the Standard Model. The graviton is a hypothetical boson which would mediate the gravitational force but has not been discovered yet.

The last discovered particle of the Standard Model was the Higgs boson H reference added??. The Higgs boson is the particle which gives other particles their mass.

2.2 Neutrino oscillations and flavor violation

Neutrino oscillation was experimentally confirmed in 1998 by the Super-Kamiokande experiment in Japan, which observed the oscillation of atmospheric neutrinos. This discovery provided strong evidence that neutrinos have mass and that they can change flavors as they propagate through space. Subsequent experiments, such as the Sudbury Neutrino Observatory (SNO) in Canada and the KamLAND experiment in Japan, further confirmed neutrino oscillations by studying solar and reactor neutrinos, respectively.

2.3 Charged lepton flavor violation

3 Mu3e experiment at PSI

3.1 The goal of the Mu3e experiment

3.2 The setup of the Mu3e experiment

3.3 The Mu3e vertex detector

4 The Detection and physics behind the vertex detector

4.1 The silicon pixel sensors

4.2 PN-junctions

4.3 Pixel Sensors

Part II

Current status of the QC

5 single QC

References

- [1] Particle Data Group. Review of particle physics. <https://pdg.lbl.gov>, 2025. Accessed: 2025-10-09.
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