Chapter 1
Introduction and outline

In this chapter we will introduce both the theoretical and experimental research described in this thesis, and mention the connection between the two.

The research in this thesis is done in the framework of the Standard Model (SM). This is a collection of gauge theories that describes all fundamental interactions known today except gravity. An important part of the SM is Quantum Chromodynamics (QCD). QCD is a relativistic quantum field theory\(^1\) based on local SU(3) gauge invariance. It is the microscopic theory of the strong interaction.

Fields in the SM correspond to particles, both fermions and bosons. The heaviest fermion in the SM is the top quark. With its mass of about 175 GeV it is much heavier than the other quarks (the mass of the next-heaviest bottom quark is about 5 GeV) and leptons (the heaviest lepton is the tau, which has a mass of 1.777 GeV).

The study of the top quark is very interesting for various reasons:

- In the SM, mass is generated by electroweak symmetry breaking. The large mass of the top quark, close to the electroweak scale, indicates that it couples strongly to the field that breaks this symmetry. The top quark could thus play an important role in understanding the generation of mass in the SM.

- In the SM, the top mass, together with the W mass, constrains the Higgs mass. Combined with a direct measurement of the Higgs mass this can be used as a consistency check of the SM.

- So far, only the top quark mass has been measured. Only detailed study will tell if the properties of the top quark are as described by the SM.

- The high top mass implies a weak coupling to gluons, making it very suitable for perturbative QCD precision studies.

\(^1\)Excellent expositions of quantum field theory can be found in books by Mandl and Shaw [1], Peskin and Schroeder [2] and Sterman [3].
The top quark’s very short lifetime (large width) ensures that its properties are not obscured by QCD hadronization. For example, its spin can be studied directly.

It is clear from this, that studies of the top quark will be among the most important at the Tevatron and the upcoming Large Hadron Collider (LHC).

The top quark was first directly observed at the Fermilab Tevatron in 1995. The discovery was made in the process where a top/antitop pair is produced through QCD interaction\(^2\). One of the Leading Order (LO) Feynman diagrams showing this interaction is given in Figure 1.1.

\[ \begin{array}{c}
\text{Figure 1.1: One of the LO Feynman diagrams for top pair production. The top quark line is thickened.}
\end{array} \]

A top quark can also be produced through the charged-current coupling (electroweak interaction). This is called single-top production, because only one top (or antitop) quark is produced. The LO Feynman diagrams for this process are given in Figure 1.2. Single-top production has not yet been observed, due to a lower cross section and much higher backgrounds for this process.

This measurement has importance because the charged-current top coupling might be particularly sensitive to certain signals of new physics. For example, in the SM, but not in various extensions, the top quark is 100% polarized when produced via the charged-current interaction, and this structure can be verified by looking at the decay products of the top.

The first part of this thesis will develop the theoretical description of single-top production: Chapter 2 describes a calculation of single-top production at LO which includes the decay of the top quark. Numerical results of this calculation are also given. In Chapter 3, we develop techniques which are needed for a Next to Leading Order (NLO) QCD calculation with massive particles. In Chapter 4 a fully differential NLO (in QCD) calculation of single-top production is presented\(^3\).

\(^2\)In Chapter 5 theoretical and experimental work that has been done on top pair production will be discussed.

\(^3\)Chapters 2, 3 and 4 are based on publications [4, 5, 6].
The second part of the thesis describes the measurement of a top cross section in recent data taken with the DØ detector at the Tevatron collider. Due to the limited availability of data, a discovery of single-top production was not possible at the time of writing of this thesis. We therefore decided to do a measurement of the top pair cross section. Because many of the techniques used in this measurement are similar to the single-top cross section measurement, this will be an excellent preparation for the single-top measurement. Moreover, top pair production is an important background to single-top production.