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Improvement of the single top-quark detection in the s-channel at the CMS Experiment

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(**Prof. Dr. Thomas Müller**)

I hereby certify that the enclosed thesis is my own work, that I have not sought or used inadmissible help of third parties to produce this work and that I have clearly referenced all sources used in the text.

Karlsruhe, XX MONTH 2018

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Abstract

Contents

1 Theoretical Background

This chapter discusses the relevant theory for the thesis. Section 1.1 gives a condensed overview of the experimental aspect of the standard model (SM) of particle physics, the framework for this work. Section 1.2 focuses on properties of the top quark, its production processes and decay modes, which will be relevant for the development and evaluation of the classifier in chapters 3 and 3.

1.1 The Standard Model of Particle Physics

The SM describes the known elementary particles and their interactions. Elementary particles are grouped into fermions and bosons based on their spin quantum number.

Fermions are particles with a spin of $1/2$. They are grouped into six quarks and six leptons, which are arranged according to their masses in three generations. The quarks are the up (u), down (d), charm (c), strange (s), top (t) and bottom (b) quark. The leptons consist of the electron (e), electron neutrino (ν_e), muon (μ), muon neutrino (ν_μ), tau (τ), tau neutrino (ν_τ). For each fermion an antifermion with same mass, but opposite electric charge, color and third component of isospin, exists. A summary of the fermions is given in table 1.1.

Table 1.1: Six leptons and six quarks constitute the fermions of the Standard Model. Particles are ordered according to their generation. Source: [4, 5]

Fermions	Generation 1	2	3	Electric charge	Color	3rd component of isospin I_3	Spin
Leptons	ν_e	ν_μ	ν_τ	0	—	$+1/2$	$1/2$
	e	μ	τ	-1		$-1/2$	
Quarks	u	c	t	$+2/3$	r, b, g	$+1/2$	$1/2$
	d	s	b	$-1/3$		$-1/2$	

Quarks carry color charge, electric charge and weak isospin - they interact with other quarks via the strong, electromagnetic and weak interaction respectively. A quark's color can take one of three charges (red, green, and blue), an antiquark one of the three anticolors (antired, antigreen, and antiblue). Due to color confinement, quarks cannot

be isolated, they are strongly bound to one another forming color-neutral composite particles (hadrons). Hadrons consist of mesons (one quark, one antiquark) and baryons (three quarks), such as the proton (uud) and the neutron (udd). Quarks from the same generation form a weak isospin doublet; particles from the same doublet behave similarly towards the weak interaction.
Leptons do not possess color charge. The three neutrinos lack additionally in electric charge and only interact through the weak nuclear force, thus being difficult to detect. The electron, muon, and tau have electric charge and interact electromagnetically.
First-generation charged particles do not decay, they constitute ordinary matter. Neutrinos do not decay either, they exist in abundance, but do not interact with matter. Other higher generation charged particles have very short lifetimes and can be observed in high-energy experiments only [8].

Gauge **bosons** mediate the forces between elementary particles and have a spin of 1. They consist of the photon γ, mediating the electromagnetic interaction between electrically charged particles, the W^+, W^- and Z bosons mediating the weak interaction and the 8 gluons g, mediating the strong interaction. They are listed in detail in table 1.2.

Table 1.2: The gauge bosons of the Standard Model are spin-1 particles that mediate the three fundamental forces described by the SM. For every boson, the interaction it participates on, the charge it couples on, its mass, spin, parity and interaction range are given. Source: [4], [2]

Boson	Interaction	Acts on	Mass (GeV)	J^P	Range (m)
8 gluons (g)	strong	color charge	0	1^-	$\approx 10^{-15}$
photon (γ)	electromagnetic	electric charge	0	1^-	∞
$W^\pm$	weak	weak charge	80.385	1	10^{-18}
Z^0			91.188		

The interactions of the SM are described by quantum field theories [6]:

- the electromagnetic interaction is described by quantum electrodynamics (QED). Because photons have no electrical charge, they do not interact with other photons,
- the strong interaction is described by quantum chromodynamics (QCD), which, as previously mentioned, forbids the existence of free color-charged particles,
- the weak interaction is described by quantumflavordynamics (QFD) [3]. The gauge bosons, left-chiral fermions and right-chiral antifermions interact weakly. Conservation of parity is therefore violated by the weak interaction, because left-handed particles transform to right-handed particles under a parity inversion.

The electromagnetic and the weak interaction are unified within the theory of the electroweak interaction. This theory predicts four massless gauge bosons, the B^0, W^0, W^1, W^2 bosons. The spontaneous symmetry breaking of the electroweak symmetry, caused by the Higgs mechanism, produces three massive gauge bosons (the Z^0 and $W^{\pm}$) and one massless (the photon γ). These gauge bosons are described by the theory as orthogonal linear combinations of the B^0 and W^0 bosons under the Weinberg angle [7].

The Higgs mechanism introduces a new complex scalar Higgs field, which in addition to providing masses to the weak gauge bosons, also couples through a Yukawa interaction with the corresponding fermion fields, generating non-vanishing fermion mass terms. The excitation of the Higgs field leads to the production of the Higgs boson. The existence of the Higgs boson was confirmed in 2012 by the ATLAS and CMS experiments at the Large Hadron Collider. It has a mass of around 125 GeV [1] and is the only spin-0 particle in the SM.

1.2 The Top Quark

2 Experimental Background

2.1 The Large Hadron Collider

2.2 The Compact Muon Solenoid Experiment

3 NN-Classifier for Top-Quark Reconstruction

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