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Arbeit zur Erlangung des akademischen Grades
Bachelor of Science

Neural network based signal-background classification for the differnetial single top+photon measurement at the ATLAS experiment

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Kurzfassung

Hier steht eine Kurzfassung der Arbeit in deutscher Sprache inklusive der Zusammenfassung der Ergebnisse. Zusammen mit der englischen Zusammenfassung muss sie auf diese Seite passen.

Abstract

The abstract is a short summary of the thesis in English, together with the German summary it has to fit on this page.

Contents

1 TO DO

1. Fix ugly citation style
2. Define pseudorapidity and other coordiantes in 4.1
3. 4.2.2 and 4.2.1 missing
4. Cite anti-k_t algorithm and study of misidentified jets in 4.2.3
5. Define coordinate systems
6. Correct Nils' points in 4
7. Correct Björn's points in 3

2 Introduction

Hier folgt eine kurze Einleitung in die Thematik der Bachelorarbeit. Die Einleitung muss kurz sein, damit die vorgegebene Gesamtlänge der Arbeit von 25 Seiten nicht überschritten wird. Die Beschränkung der Seitenzahl sollte man ernst nehmen, da Überschreitung zu Abzügen in der Note führen kann. Um der Längenbeschränkung zu genügen, darf auch nicht an der Schriftgröße, dem Zeilenabstand oder dem Satzspiegel (bedruckte Fläche der Seite) manipuliert werden.

3 Single top quark production with a photon in the Standard Model

3.1 A brief overview of the standard model

The standard model (SM) of particle physics, a so-called "gauge theory", describes today's best knowledge of elementary physics. In the SM, there are two groups of particles and three fundamental forces of nature: the electromagnetic force, the strong nuclear force and the weak nuclear force. Every force coincides with an elementary particle, called a boson that acts as a force carrier. The second group of particles, the fermions, only interact with these force-carrying bosons if they have specific values for their quantum numbers.

The fermions have spin $s = \frac{1}{2}\hbar$ and can be divided into two separate groups. The first group, named quarks, are colour charge carrying fermions. There are three up-type quarks (up, strange and truth) with an electric charge of $q = +\frac{2}{3}e$ and three down-type quarks (down, charm and beauty) with an electric charge of $q = -\frac{1}{3}e$. The second group are the leptons. Three leptons have an electric charge of $q = +1e$. Furthermore, each of these leptons has a corresponding uncharged lepton partner called a neutrino. Three different families further categorize leptons and quarks. These families are ordered by mass and consist of an up-type quark, the corresponding down-type quark, a lepton and the corresponding neutrino. There is an anti-matter particle equivalent for all fermions where every charge-like quantum number has the opposite sign.

Particles with integer spin are called bosons. The SM lists four different bosons, called gauge bosons, with spin $s = 1$: *gluons*, *photons*, Z and $W^{\pm}$. The Higgs boson is the only boson with spin $s = 0$. Gluons are colour charged and responsible for the strong nuclear force. They only couple to colour charged particles, including themselves. Photons carry the EM force to electrically charged particles. The massive bosons, Z and $W^{\pm}$ are responsible for the weak nuclear force. They couple to particles with isospin. The weak force is the only way that neutrinos can interact with matter. Additionally, the $W^{\pm}$ boson is electrically charged, $q = \pm 1e$, and changes the flavour of a quark when coupling to it. The Higgs boson explains how particles have mass. The boson arises from the electroweak symmetry theory and gives mass to particles via the Higgs mechanism. The interaction with the Higgs field is purely a product of electroweak symmetry breaking and is therefore not considered one of the fundamental forces.

A summary of the elementary particles in the standard model is given in 3.1.

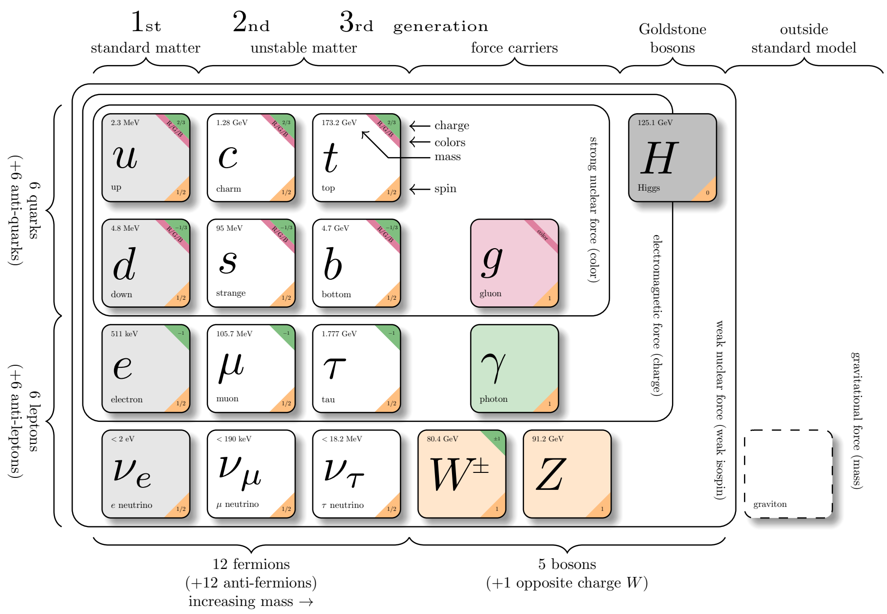

Figure 3.1: Elementary particles of the standard model alongside their propertie [Bur16].

3.2 The $tq\gamma$ process in the standard model

The top quark (or truth quark) is an up-type quark and the most massive quark of the standard model with a mass of $m_t = 173.76 \pm 0.3\,\text{GeV}(S = 1.2)$ [Zyl+20]. It sometimes to a photon due of it's $q = +\frac{2}{3}e$ electric charge. In addition, the top quark has a colour charge and can therefore couple to gluons. The quark also interacts weakly because of its isospin of $I_z = +\frac{1}{2}$. Finally, the top quark has a very short decay width of $\mathit{\Gamma} = 1.42^{+0.19}_{-0.15}\,\text{GeV}(S = 1.4)$ [Zyl+20] because of its high mass. For this reason, top quarks cannot build any bound states and always decay shortly after production. Top quarks are therefore never observed directly. Instead, only their decay products are observable and can be retraced back to the top quark.

The first discovery of the top quark was made at the Tevatron in 1995 during a proton-antiproton collision experiment (CITE). In 2009, the D0 [Aba+09] and CDF [Aal+09] collaborations also separately confirmed the measurement of the single-top-quark-process (tq) of the standard model at the Tevatron. The combined results are available in Ref. [Gro09]. The CMS experiment at the LHC found evidence for the single-top-quark-process with an additional photon (tqGamma) with a standard deviation of $\sigma = 4.4$. The fiducial cross section was measured to be $\sigma(pp \rightarrow tq\gamma)(t \rightarrow \mu\nu b) = 115 \pm 17(stat) \pm 30(syst)\,\mathrm{fb}$ for transverse momentum $p_T^\gamma > 25\,\mathrm{GeV}$ (CITE). (ADD BJÖRN PAPER REFERENCE).

For the tqGamma-process, one gluon provided by the protons (also called parton) produces a bottom-antibottom-quark pair. The bottom quark then exchanges a W-boson with an arbitrary quark-parton, turning the bottom quark into a top quark and changing the flavour of the quark-parton. This top-quark then sends out a photon. The decay mode of the top quark follows this process. Top quarks decay by emitting a W^+-boson and turning into a bottom quark. The W^+-boson then decays shortly after into an antilepton and neutrino pair or a quark-antiquark pair of opposite types.

In Figure 3.2 the Feynman-diagram for the single-top+photon production is drawn.

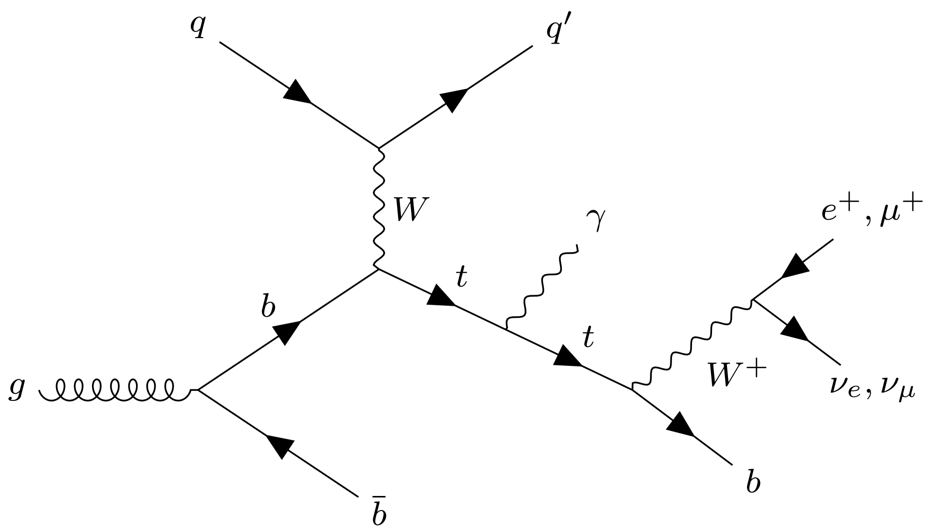

Figure 3.2: Feynman diagram of the $tq\gamma$-process in the standard model.

4 Measurement of $tq\gamma$

1. Koordinaten definieren und anwenden
2. Explain why $t\bar{t}\gamma$ is close to $tq\gamma$. Mit crossection
3. Anit k_t besser erklären
4. Reconstruction of leptons
5. Reconstruction of photons

4.1 The ATLAS Experiment

The European Organization for Nuclear Research, known as CERN, located in Geneva, has various experiments studying elementary particles through the collision of heavy ions and protons. The Large Hadron Collider (LHC), the largest particle accelerator of CERN, has a circumference of 27 km and can collide particles with a center of mass energy of up to $\sqrt{s} = 13.6\,\text{TeV}$.

The LHC consists of four extensive experiments: the ALICE, the LHCb, the CMS and the ATLAS experiments. The research in this thesis is done with the help of the largest of these experiments, the ATLAS experiment. Figure 1 visualizes the structure of the ATLAS detector. The detector is built symmetrically around the particle beam and can be divided into three subdetectors.

The inner detector tracks charged particles just after the collision. It consists of three different systems of sensors in a magnetic field parallel to the beam. These sensors are the pixel detector, the semiconductor tracker which works with silicon strips and a transition radiation tracker to track particles with gas-filled tubes.

In the EM calorimeter, metal layers (tungsten, copper or lead) absorb incoming particles and convert them into lower-energy particles called a shower. The calorimeters detect "showers" produced by electrons (and positrons), photons and hadrons. Hadrons do not deposit all of their energy into the EM calorimeter; they get absorbed by steel layers in the hadronic calorimeter. Plastic scintillating tiles then produce photons that get converted into an electric current.

The muon spectrometer measures trajectories of muons with the help of a magnetic field. The spectrometer detects muons in the range of $|\eta| > 2.7$. Monitored drift tubes measure for pseudorapidities up to $|\eta| = 2.0$ and cathode strip chambers cover higher pseudorapidities.

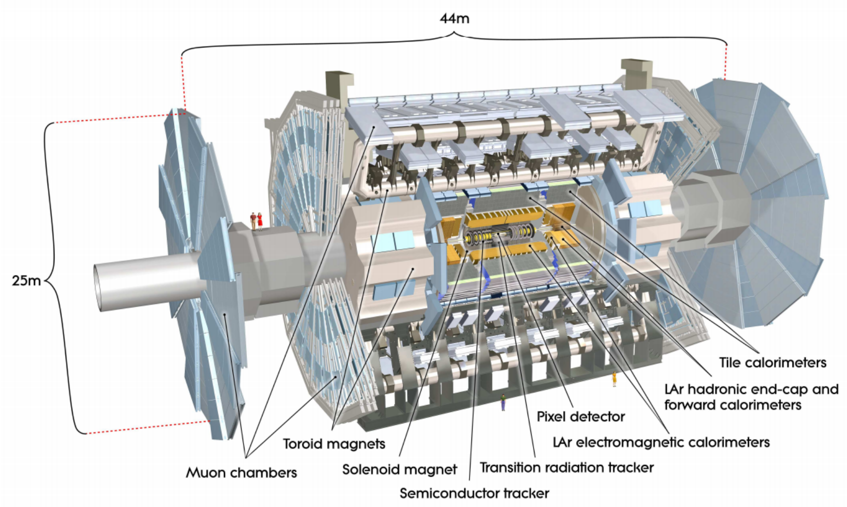

Figure 4.1: Schematic visualisation of the ATLAS Detector [Col+08].

4.2 Object Reconstruction at the ATLAS experiment

4.2.1 Reconstruction of photons

?

4.2.2 Reconstruction of leptons

?

4.2.3 Jets

Jets are reconstructed from clusters of energy depositions of mostly mesons and fewer baryons that result from the separation of two quarks (color confinement) (**NOTE:**

Jets sind tatsächlich ausschließlich Schauer aus quarks. EM-Schauer sind keine Jets). They are reconstructed with the help of the anti-k_t algorithm [**anti_k_t**] with a radius parameter of $R = 0.4$. This algorithm reconstructs jets by first identifying the particle source via the jet energy scale. It is then required that the jet has a transverse momentum of $p_T > 25\,\mathrm{GeV}$ and $|\eta| < 4.5$.

Detector noise can lead to the misidentification of a jet. The nature of these misidentified jets has been studied thoroughly [**70**] and a so-called "jet cleaning procedure" is used to tag them. Any event containing at least one "bad" jet is removed.

4.2.4 Missing transverse momentum E_T^{miss}

If all particle products are considered, there should be no magnitude for the sum of the transverse momentum p_T of all particles. Any measured magnitude is therefore attributed to an unmeasured particle. The missing transverse energy E_T^{miss} is consequently defined as the negative of this sum and assinged to a neutrino.

4.3 Background contributions from similar processes

Various different processes besides $tq\gamma$ are also accepted by the criteria for event selection **??**. For the scope of this thesis, contributions from these processes are considered background. The process $t\bar{t}\gamma$ holds the most similar decay product as it's products can be identical to the products of $tq\gamma$. Following processes is the production of a W-boson with jets, a Z-boson with jets and $t\bar{t}$.

Table 4.1 lists these and the rest of the processes contributing to the background.

	Process
1	$tq\gamma$
2	$t\bar{t}\gamma$
3	$W\gamma + jets$
4	$Z\gamma + jets$
5	$t\bar{t}$
6	$schan$
7	tW
8	$tchan$
9	VV
10	$W + jets$
11	$Z + jets$

Table 4.1: List of SM processes that contribute to background noise in the measurement of $tq\gamma$.

5 Monte Carlo samples and event selection

5.1 Generation of Monte Carlo samples

The framework $MadGraph5\_aMC@NLO$ is used for Monte Carlo (MC) simulations of the considered $tq\gamma$ process. $MadGraph5$ is a matrix element generator that allows the interfacing of different packages for further simulation. The simulated events are generated at next-to-leading order (NLO) at the t-channel of single top production. The generator is interfaced to the package *Pythia* $v8.240$, which provides parton showers. The $MadSpin$ and *EvtGEN* $v1.6.0$ packages give decay simulations of the top and bottom quark, respectively. Here, only leptonic decays of the top quark are considered.

Moving on to background processes, the $t\bar{t}$ process is modelled at leading order (LO) also using $MadGraph5\_aMC@NLO$ $v2.3.3$ interfaced to *Pythia* $v8.212$. Simulation of $W\gamma$+jets and $Z\gamma$+jets events are produced at NLO using the *Shepra* $v2.2.2$ and *Shepra* $v2.2.4$ packages. For the $t\bar{t}$ process and t-, s-, tW-channels *Powheg-Box* is used where *Pythia* $v8.230$ is again used as the showering program. The modeling here is performed in NLO in QCD.

The table 5.1 gives a summary of the generated samples and their generators. In addition, the sample IDs (DSID) is also provided in the table.

Process	Generator	DSID
$tq\gamma$	*MadGraph5_aMC@NLO + Pythia8*	412147
$t\bar{t}\gamma$	*MadGraph5 + Pythia8*	410389
$W\gamma + jets$	*Sherpa* 2.2.2	3645[21-35]
$Z\gamma + jets$	*Sherpa* 2.2.4	3661[40-54]
$t\bar{t}$	*Powheg + Pythia8*	410470
single top	*Powheg + Pythia8*	41065[8-9] , 41064[4-7]
$W + jets$	*Sherpa* 2.2.1	3641[56-97]
$Z + jets$	*Sherpa* 2.2.1	3641[00-41]
Diboson	*Sherpa* 2.2.2	3633[55-60] , 363489 , 36425[0, 3-5]

Table 5.1: List of generated samples alongside their generators and DSID.

5.2 Event selection

The selection criteria for events must hold the necessary conditions for a $tq\gamma$-process. It also needs to have enough restrictions to reduce background contributions as much as possible. Signal events have precisely one lepton, at least one photon and one b-tagged jet in the final state. The lepton should have a transverse momentum higher than 20 GeV, the photons momentum higher than 27 GeV and the b-tagged jet has to pass the $DL1r$-algorithm with a 70% working point.
Additionally, the missing transverse energy E_T^{miss} ought to be above 30 GeV to account for the neutrino in the decay mode. Finally, to reduce leading background contributions from the $Z \to ee(\to \gamma)$ process, the invariant mass of the leading photon and an electron candidate $m_{e\gamma}$ is set to be in the range $80\,\text{GeV} < m_{e\gamma} < 110\,\text{GeV}$. Altogether, this makes up the following requirements for selected events:

1. At least one photon γ with $p_T > 20\,\text{GeV}$
2. Exactly one lepton with $p_T > 27\,\text{GeV}$
3. $E_T^{miss} > 30\,\text{GeV}$
4. Exactly one b-tagged jet passing 70% working point (WP) of the $DL1r$-algorithm.
5. Invariant mass of leading photon and electron candidate between values $80\,\text{GeV} < m_{e\gamma} < 110\,\text{GeV}$

6 The Neural Network used for signal-background classification

6.1 Short introduction to neural networks

6.2 The neural network architecture

6.3 Input features for the neural network

6.4 Performance and distribution of the NN output

7 Differnetial analysis of the NN output

7.1 Correlations of input features with the NN output

7.2 NN output distribution dependence on photon p_T and fjet+photon energy

8 Conclusions

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