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Part 1

Introduction

With the discovery of the Higgs boson at the LHC in the year 2012, the last missing piece of the Standard Model of particle physics was found [1, 2]. Thus, all particles contained in the Standard Model are discovered and all of its parameters are measured, many of them with accuracies at the per mille level. Up to now, the Standard model has been tested at many particle physics experiments and has proven its ability to explain - and even predict - experimental results in a remarkable way.

Nonetheless, there are strong reasons to believe that the Standard Model is not the ultimate theory of particle physics. Experimental observations as well as theoretical considerations have led to the belief that there exists physics beyond the Standard Model. For instance, the observation of Dark Matter cannot be explained from a particle perspective within the Standard Model. From a theoretical point of view, a major concern is related to the occurrence of quadratic divergencies in the calculation of the Higgs boson mass at higher radiative orders. The Higgs boson mass is measured at a value of around 125 GeV, which is considered very low regarding the huge radiative corrections at the Planck scale ($\sim 10^{19}$ GeV). This raises the question of what kind of mechanism is responsible for the stabilisation of the Higgs boson mass at the electroweak scale. Among others, these shortcomings of the Standard Model have led to strong efforts to develop theories that go beyond the Standard Model of particle physics.

One of these theories is able to solve the above mentioned problems by imposing a fully new symmetry into the Lagrangian formulation of particle physics, a so-called supersymmetry (SUSY). This symmetry relates bosons and fermions by new fermionic generators and leads to the prediction of a supersymmetric partner particle for each of the particles contained in the Standard Model. This could have drastic implications for the phenomenology of particle physics, since a doubling of the particle content is predicted. Therefore, a variety of searches for supersymmetric particles has been performed at many particle physics experiments.

This PhD thesis presents a search for supersymmetric particles in 19.7 fb^{-1} of data, taken in the year 2012 at a centre-of-mass energy of 8 TeV at the CMS detector. The search is motivated by supersymmetric models with nearly mass-degenerate lightest ($\tilde{\chi}_1^0$) and next-to lightest ($\tilde{\chi}_1^{\pm}$) supersymmetric particles that have not yet been investigated by existing SUSY searches. A small mass splitting between the two particles can lead to a long-lifetime of the next-to lightest supersymmetric particle $\tilde{\chi}_1^{\pm}$ because of phase space suppression. The charged $\tilde{\chi}_1^{\pm}$ can therefore appear as a reconstructed track in the inner tracking system of the CMS detector. At rather low $\tilde{\chi}_1^{\pm}$ lifetimes, the $\tilde{\chi}_1^{\pm}$ decays inside the tracker and the reconstructed track can be very short. Furthermore, since the masses of the supersymmetric particles are in general higher than their Standard Model partners, $\tilde{\chi}_1^{\pm}$ can be heavy and can therefore deposit much higher energies in the tracker compared to minimally ionising Standard Model particles. Therefore, the analysis strategy of the here presented analysis is to search for highly ionising, short tracks. It is the first analysis that incorporates tracks with down to three measurement and that makes use of the energy information of the silicon pixel tracker, which has been subject to an energy calibration within this thesis.

The second research objective of this thesis is a measurement of the jet transverse-momentum resolution at a centre-of-mass energy of 8 TeV at CMS. The knowledge of the jet p_{T} resolution is a crucial ingredient for many analyses at CMS, e. g. [3–5]. In order to exploit the good calorimeter energy resolution of the CMS experiment, the measurement is performed using $\gamma +$ jet events, where the photon energy can be used as a measure for the true jet transverse momentum. The applied method is based on earlier measurements [6, 7] but is further developed within this thesis in order to consistently account for the influence of additional jet activity on the jet transverse-momentum response.

The thesis is structured into six main parts.

Part 2: This part summarises the theoretical foundations, comprising an introduction to the Standard Model of particle physics as well as to its supersymmetric extensions. A special focus is on the theoretical description and phenomenology of long-lived particles in supersymmetric models.

Part 3: Within this part, the experimental setup is presented, including an introduction to the Large Hadron Collider and the CMS experiment as well as a description of the algorithms used for event reconstruction and particle identification at CMS. Finally, a short introduction into the techniques of event simulation is given.

Part 4: In this part, the search for highly ionising, short tracks is presented. It starts with a motivation and an outline of the general search strategy. Afterwards, the calibration of the silicon pixel tracker is described and its impact on the search is discussed. Subsequently, the event selection is described and the background estimation methods are introduced. Finally, the results are presented and interpreted in the context of supersymmetric models with long-lived $\tilde{\chi}_1^{\pm}$. The last chapter of this part is devoted to a conclusion and discussion of the most important findings.

Part 5: This part presents the measurement of the jet transverse-momentum resolution in $\gamma +$jet events recorded at CMS at $\sqrt{s} = 8$ TeV. It starts with a motivation and a presentation of the general approach to the measurement. The introduction of the event selection is followed by a thorough description of the methodology. Afterwards, the systematic uncertainties are discussed. Finally, the results are presented, followed by a conclusion and discussion.

Part 6: This part concludes and summarises the presented analyses and results.

Part 2

Summary

In the year 2012, a variety of different searches and measurements were performed at the CMS experiment. The main tasks were to search for physics beyond the Standard Model as well as to measure Standard Model parameters and important performance parameters of the CMS detector. This thesis contributed in a twofold way to the physics program of CMS.

First, a search for physics beyond the Standard Model by the selection of highly ionising, short tracks was performed. The design of the search was strongly motivated by supersymmetric extensions of the Standard Model that include long-lived charginos decaying inside the tracker into the lightest supersymmetric particle, the neutralino. Because of the higher masses of supersymmetric particles, the chargino is expected to deposit much higher amounts of energies in the tracking system compared to the Standard Model background. Furthermore, the search was designed to target supersymmetric models not yet excluded, i. e. models with chargino lifetimes of the order of $c\tau \approx 1 - 30\,\mathrm{cm}$ where most of the charginos even decay in the first layers of the tracker. Therefore, for the first time, reconstructed tracks down to three tracker hits were incorporated and an energy measurement was performed. For this purpose, energy information from the silicon pixel detector was exploited for the first time at CMS. The energy information provided by the pixel tracker could only be used because a well calibrated tracking system was ensured. This was achieved by the calibration of the pixel tracker energy information which was performed within this thesis.

The background expectation was estimated mainly with data-based techniques and consisted mostly in fake tracks, i. e. tracks that are not associated to one single particle. A selection was performed in four different signal regions in order to increase the search sensitivity to different chargino lifetimes and masses. The major challenges of this search consisted in the estimation of the Standard Model background because of the low event yield in most of the control regions. Therefore, the search sensitivity is mainly limited by systematic uncertainties arising from limited size of simulated samples as well as control regions in data.

The search for highly, ionising short tracks was performed with $19.7\,\mathrm{fb}^{-1}$ of $8\,\mathrm{TeV}$ data recorded at the CMS experiment in the year 2012. The results were compatible with Standard Model expectations. Thus, this result was used to constrain the supersymmetric parameter space with wino-like charginos. With this search supersymmetric models with long-lived charginos down to lifetimes of 2 cm for chargino masses of 100 GeV and down to 70 cm for masses of 500 GeV could be excluded. Current limits could be confirmed and slight improvements of the order of 10-30 GeV were achieved.

The second contribution of this thesis contains the measurement of the jet transverse-momentum resolution at 8 TeV at the CMS detector. The jet p_{T} resolution is a crucial ingredient for analyses at CMS relying on a good understanding of the quality of the jet p_{T} measurement, e. g. physics beyond the Standard Model where QCD-multijet background plays a major role or Standard Model measurements of the QCD cross section or top quark differential measurements. The method of the resolution measurement based on earlier methods but is the first measurement that accounted for the fundamental non-Gaussian behaviour of the measured resolution in exclusive bins of further jet activity. The Gaussian behaviour can be recovered when separating events by the direction of further jets in the event. By this separation the validity of the method could be retained and well performing method was achieved. The results are compatible with the jet p_{T} measurement performed on dijet events. As the main application of the resolution measurement is the adjustment of the simulated resolution to the resolution measured in data, the results are presented as data-to-simulation scale factors. In various pseudorapidity regions up to $|eta| = 2.3$, the scale factors vary between 7% and 20% with uncertainties between 3% to 8%. The results of this measurement will be accessible in a paper that is still in preparation.

With the two presented analyses, this thesis could contribute highly to ????

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