To the bottom of the stop: calibration of bottom-quark jets identification algorithms and search for scalar top-quarks and dark matter with the Run I ATLAS data

Pani, P.

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Part 1

Experimental and theoretical introduction

Introduction

In the last century high energy physics has made incredible steps forward toward the comprehension of the nature of our universe, its matter content and the interactions of that matter. The Standard Model (SM) [1–4] provides a cogent description of all known subatomic particles and their quantum interactions (strong, weak and electromagnetic). The SM predictive power has been tested to unprecedented precision, with the recent discovery of a Higgs boson by the Large Hadron Collider (LHC) experiments [5, 6] completing the last piece of the particles puzzle. Nevertheless the SM is believed to be an incomplete theory, due to a number of questions that are currently unanswered by the theory.

Dark Matter and Dark Energy represent 96% of the content of the universe and their nature is currently unknown. The remaining four percent is dominated by ordinary (baryonic) matter. The SM is also unable to explain the apparent lack of antimatter in the universe, which should have been made in the Big Bang in equal amount with matter. Furthermore the theory cannot explain neutrino masses and lacks a fundamental explanation for the quarks, leptons and neutrino mass hierarchy and mixing and the existence of three generations of particles. Finally, unification of gravity with the other forces is not possible within the SM theoretical framework.

These and many more open questions about nature call for extensions of the SM. These theories, such as Supersymmetry (SUSY), compositeness and extra dimensions, string theory and multiverses, hidden sectors, extended Higgs sectors and top partners, usually answer some or all of the questions listed above and predict new phenomena, often at the TeV energy scale. Figure 1 gives an schematic representation, presented at the Snowmass 2013 meeting [7], of the different coverage that each type of theory, depicted as *big ideas* in the report, gives to each category of currently open questions. As it stands out, Supersymmetry is one of the most compelling of these ideas and it is one of the main focuses of the research programs at

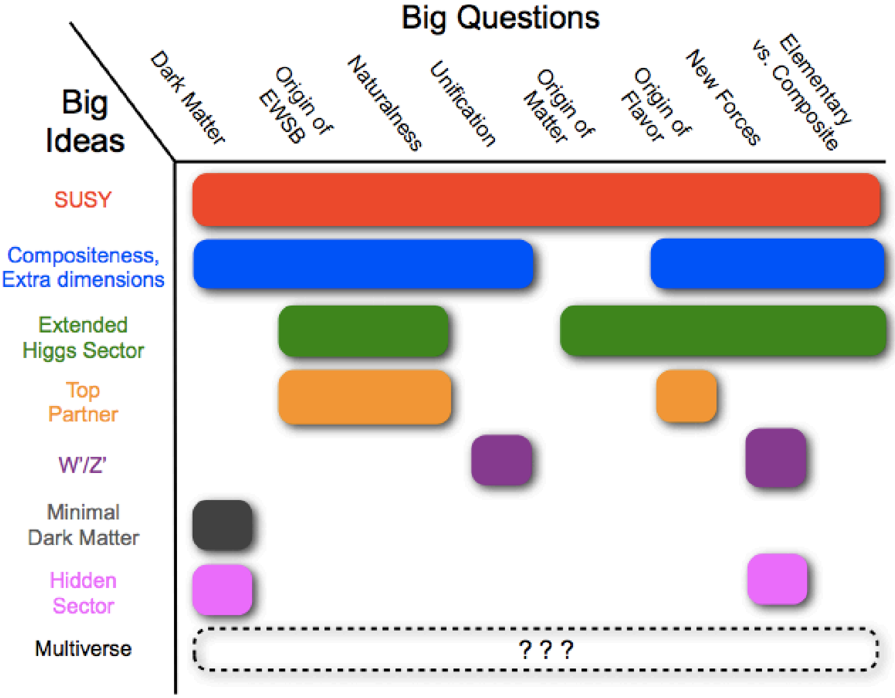

Figure 1: *Representation presented at the Snowmass 2013 meeting [7] of the issues unexplained by the current scientific paradigm* (big questions) *and the theoretical models* (big ideas) *proposed as a solution to them and as an extension of the current theory of particle physics.*

the LHC experiments.

The LHC is currently the most powerful pp collider. The first Run lasted from 2010 to 2012. In this period the accelerator has delivered a total integrated luminosity of pp collisions of 5 and 20 fb^{-1} at a centre-of-mass energy of 7 and 8 TeV, respectively. The A Toroidal LHC ApparatuS (ATLAS) experiment is one of four experiments recording the collisions delivered by the LHC. In these three years, a large crew of physicists and technicians has contributed to the operation of the ATLAS detector, in order to guarantee the highest efficiency in recording the data delivered by the accelerator and the healthy functioning of all sub-detectors.

In 2011, the main focus of the ATLAS experiment has been not only to probe for the first time physics at the energy frontier, but also to improve the understanding and calibration of the detector and the tuning and validation of the Monte Carlo simulation used to model the SM (and new physics) processes. The analysis presented in Part 2 of this thesis is a study of the reliability of the Monte Carlo simulation of jets originating from bottom quarks (b-jets), the response of the detector to them and the performance of the algorithms used for their identification. The study is based on the 5 fb^{-1} of data collected in 2011 and it was driven by the need of understanding the reasons behind the calibration factors needed to match the simulation to the experimental data.

The dataset collected by ATLAS in 2012 is four times bigger than the one in 2011 and the higher centre-of-mass energy results in a higher production cross section for one of the most intriguing particles predicted by SUSY: scalar top quarks (top squarks). Part 3 presents a search for top squarks in final states with one isolated lepton, b-jets and missing transverse momentum.

Outline of the thesis

This thesis is divided in three Parts. The first one gives a theoretical and experimental introduction to the presented analyses. Chapter 1 is a theoretical introduction to Supersymmetry, mostly focused on the top squark phenomenology, and to the connections between top quarks, neutralinos and Dark Matter. Chapters 2 and 3 introduce the experimental framework: the ATLAS detector and the details about the reconstruction and identification of all the particles used in the presented analyses. Particular attention is devoted in Section 2.3 to performance monitoring and improvement of the ATLAS inner tracking system.

The second Part of this thesis describes a calibration of b-jet identification algorithms, based on a method that exploits fully reconstructed B hadrons that are associated to the b-jets. The main results of this work will be summarised in an ATLAS publication [8], currently in preparation. The strategy of the analysis is introduced in Chapter 4, the validation of the background estimate is given in Chapter 5 and the analysis of the results based on 5 fb^{-1} of data collected at $\sqrt{s}$ = 7 TeV are presented in Chapter 6.

The last part of this thesis is devoted to the description of a search for top squark pairs in final states with one isolated lepton, four jets of which at least one identified as a b-jet and missing transverse momentum. The results of this analysis are part of an ATLAS publication [9]. The search strategy, the backgrounds and the quantities used to discriminate top squark events from the SM processes are introduced in Chapter 7. In Chapter 8 the signal selections are described, with particular attention to the selection optimisation for top squarks decaying into a chargino and a b-quark ($\tilde{t} \rightarrow b\ \tilde{\chi}^{\pm}$). In the same chapter, the background estimate and validation for all the analysis sections is described. The results of the search are given in the last chapter (Ch. 9). The analysis results are also interpreted, in the same chapter, in terms of upper limits of Dark Matter contact operators in the context of Effective Field Theories. These results will be also part of an ATLAS publication [10], currently in preparation.