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Priscila de Aquino

Beyond Standard Model Phenomenology at the LHC

Doctoral Thesis accepted by
the Katholieke Universiteit Leuven and the
Université Catholique de Louvain, Belgium

Springer

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Supervisors' Foreword

The main physics event of 2012 was the announcement on July the 4th of the discovery of a new boson at CERN with a mass close to 126 GeV.

The on-going analysis of the properties of the particle discovered last year points with increasing evidence to the long awaited for particle related to the Brout-Englert-Higgs mechanism introduced in the 1960s. The main focus of the investigations at the LHC experiments now shifts to the possibility of finding other high-energy phenomena such as supersymmetry or extra dimensions, in particular in the forthcoming run at 13 TeV energy in 2015. While evidence of new physics at the TeV scale is mounting through astrophysical/cosmological observations and neutrino experiments, the challenges for a direct observation at the LHC are formidable. The discovery of the new boson is a major breakthrough which was also based on how precise knowledge and predictions of its properties in the Standard Model. Yet it took almost 50 years. Looking for new physics is much more difficult as options are wide open and one in many, even unexpected possibilities could turn to be the one chosen by nature. That is the challenge at the basis of this thesis which, starting from one of such class of models, faces the problem of how to search for it via accurate and flexible computer simulations.

After an introduction to the physics of the Standard Model and beyond, this work presents the methods of investigation of the LHC data in the context of extensions of the Standard Model featuring gravitons and gravitinos. The production of these particles in association with jets is studied as one of the most promising signatures to discover new physics at the LHC. In this work, Priscila uses the most advanced techniques, such as algorithms allowing the computation of Feynman graphs and helicity amplitudes, to help in the development of new simulation tools specialized for graviton/gravitino-like particles. These tools are subsequently employed revealing its power.

For interpreting the data from the LHC, such tools are currently being used and have shown to be crucial for the characterization of the properties of the new boson. They will become even more relevant if new physics will be detected at the LHC. Any student in theoretical physics as well as experimentalist in high-energy physics will find in this work a lively description of the strategies as well as of the cutting-edge technologies employed in the search for new physics in collider experiments.

Leuven, April 2013 Prof. Dr. Antoine Van Proeyen
Louvain-La-Neuve, April 2013 Prof. Dr. Fabio Maltoni

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In the vastness of space and the immensity of time,
it is my joy to share a planet and an epoch with you.
Carl Sagan

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Priscila de Aquino

Contents

Acronyms

ADD	Arkani-Hamed-Dimopoulos-Dvali theory (large extra dimensions)
ALICE	A Large Ion Collider Experiment
ALOHA	Automatic Libraries of Helicity Amplitudes for Feynman diagram computations
ATLAS	A Toroidal LHC Apparatus
BEH	Brout–Englert–Higgs
BSM	Beyond Standard Model
CERN	European Organization for Nuclear Research
CKM	Cabibbo–Kobayashi–Maskawa matrix
CMB	Cosmic Microwave Background
CMS	Compact Muon Solenoid experiment
CP	Charge-Parity
GMSB	Gauge Mediated Supersymmetry Breaking
IPHC	Institut Pluridisciplinaire Hubert Curien
KK	Kaluza-Klein
KU Leuven	Katholieke Universiteit Leuven
LEP	Large Electron–Positron Collider
LHC	Large Hadron Collider
LHCb	Large Hadron Collider beauty experiment
LINAC	LINear ACcelerator
LO	Leading Order
NASA	National Aeronautics and Space Administration
NLO	Next-to-Leading Order
NNLO	Next-to-Next-to-Leading Order
MACHO	MAssive Compact Halo Object
MGM	Massless Graviton Model
MSSM	Minimal Supersymmetric Standard Model
PDF	Parton Distribution Function
PS	Proton Synchrotron
QCD	Quantum Chromodynamics
QED	Quantum Electrodynamics
RS	Randall–Sundrum theory (warped extra dimensions)
SM	Standard Model

SPS	Super Proton Synchrotron
SUSY	Supersymmetry
UCL	Université Catholique de Louvain
UFO	Universal FeynRules Output
USP	Universidade de São Paulo
VUB	Vrije Universiteit Brussel
WIMP	Weakly Interacting Massive Particles
WMAP	Wilkinson Microwave Anisotropy Probe

Abstract

The Standard Model of fundamental particles and their interactions is one of the most successful theories in physics. In particular, up to the weak scale (a few hundreds of GeV) it agrees to a great degree with a large set of experimental data. However, there are several theoretical reasons, such as the so-called "Hierarchy Problem", as well as experimental ones, such as the neutrino masses and the evidence for dark matter in the Universe, to expect that something new (particles and/or interactions) could lie at TeV scale. Hints and/or answer(s) to these fundamental questions will be provided by the Large Hadron Collider (LHC), a proton–proton collider running at high energies.

The present thesis aims to explore new physics at the LHC through phenomenological studies that employ simulations and computational tools to directly link theories with experimental data. In particular, the focus is on Beyond Standard Model theories that can incorporate a quantum description of gravity, such as extra dimensional theories, Supersymmetry and yet a simplified model where the constant of Newton is scale dependent. Phenomenological analyses are performed in which graviton and gravitino emission in combination with multiple jets are investigated at hadron colliders. Inclusive samples are generated by merging matrix element with parton shower descriptions, and validated by a comparison against next-to-leading order QCD calculations. Predictions for relevant observables at the LHC and Tevatron are obtained.