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Stefano Manzoni

Physics with Photons Using the ATLAS Run 2 Data

Calibration and Identification, Measurement of the Higgs Boson Mass and Search for Supersymmetry in Di-Photon Final State

Doctoral Thesis accepted by
the Università degli Studi di Milano, Milano,
Italy and Sorbonne Université, Paris, France

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To Cristina,
and my beloved family

Supervisors' Foreword

A Ph.D. thesis is a journey into the unknown, a new and different adventure each time. It provides the opportunity to explore the limits of present knowledge and a chance to extend them, even if that might be just by a small amount. This is particularly true for experimental particle physics, which constitutes one of the privileged paths to improve our understanding of the fundamental structure of our universe, in terms of a theory of elementary particles and their interactions. Progress in experimental particle physics comes essentially from two sources: more and more precise measurements of processes already observed, and searches for new phenomena, not observed yet, either predicted by the current theory or—even more excitingly—not expected in its context. This is only possible through sophisticated analyses of the data coming from incredibly complex detectors. A deep and precise understanding of the experimental apparatus is therefore mandatory. A successful thesis in particle physics comes out from a well-balanced mixture of all these aspects carried on by a talented and determined student—multiple ingredients that were all present in Stefano's Ph.D. thesis work.

In this dissertation, Stefano first presents the theoretical framework that currently describes most of the microscopic phenomena observed in nature, the Standard Model (SM) of particle physics, with a particular emphasis on its most crucial, long sought-for, and recently discovered particle, the Higgs boson. The discussion proceeds then through the description of the theoretical issues of the SM as well as its limitations in accounting for a few observations, mainly from astrophysical and cosmological observations, that hint to the need of an extension of the model, which naturally brings to the introduction of Supersymmetry, one of the most favored theoretical solutions at least before latest the LHC results. The common thread in Stefano's work is the measurement or search of processes leading to final state signatures that contain photons. For this reason, the next chapter of the manuscript, which describes the experimental apparatus—the ATLAS detector—used to collect the data analyzed in this thesis, focuses in particular on the most relevant performance issues connected to the photon reconstruction, calibration, and identification. Finally, the reader is led to the core of Stefano's research work: the precise measurement of the properties of a known process or particle (the mass of the Higgs boson) and the search for an evidence of phenomena not predicted by the standard model, by looking for an excess, over the expected SM background, of events with two photons and large transverse momentum imbalance from undetected particles predicted in some Supersymmetry scenarios.

As discussed above, the manuscript touches several core items in particle physics spanning from the phenomenology to the detectors description. We believe this makes the document a pleasant reading: an experienced reader might appreciate the importance of the studies in the particle physics context and the quality of the presented material, while we hope a nonexpert reader could get a feeling on how amazing, frustrating, and exciting experimental particle physics could be.

On a more personal note, a Ph.D. thesis is not simply a text; it is also the culmination of an intense period of one's life, during which—besides the intellectual and organizational qualities required for the successful completion of the project—a student has to demonstrate human qualities such as the ability to collaborate with other colleagues, to listen to and learn from others, to convince people about the soundness of the methods developed, and to defend his own results. As his supervisors, we have been able to assess all these qualities in Stefano: from this point of view, Stefano's project was really an occasion of personal and scientific growth not only for the student—we hope—but certainly also for the supervisors.

Milan, Italy
Paris, France
May 2019

Prof. Leonardo Carminati
Dr. Giovanni Marchiori

Abstract

The work presented in this manuscript is based on the proton-proton collision data from the Large Hadron Collider at a center-of-mass energy of 13 TeV recorded by the ATLAS detector in 2015 and 2016, corresponding to an integrated luminosity of 36 fb^{-1}.

The research program of the ATLAS experiment includes the precise measurement of the parameters of the Standard Model (SM) and the search for signals of physics beyond the SM. Both of these approaches are pursued in this thesis, which presents two different analyses. The first one is the measurement of the Higgs boson mass in the di-photon decay channel. The measured value of the mass is $m_H = 124.93 \pm 0.40$ GeV. Its combination with a similar measurement in the four-lepton Higgs boson decay final state is presented and with the mass measurements performed with the data collected by the ATLAS detector in 2011 and 2012. The value of the Higgs boson mass obtained from the combined measurement is $m_H = 124.97 \pm 0.24$ GeV.

The second analysis is based on the search for production of supersymmetric particles (gluinos, squarks, or winos) in a final state containing two photons and missing transverse momentum. No significant excess with respect to the SM background is observed, and lower limits on the gluino, squark, and wino masses are set in the context of a generalized gauge-mediated Supersymmetry breaking model with a bino-like next-to-lightest supersymmetric particle.

Finally, ATLAS detector performance studies (electron and photon energy calibration and measurement of the electron to photon misidentification probability), which are key ingredients for the two analyses introduced before, are also performed and described.

Acknowledgements

At the end of my Ph.D., there are a lot of people I want to thank for their precious help and support during these years.

First, I want to thank my supervisors Prof. Leonardo Carminati and Dr. Giovanni Marchiori. This thesis would not have been completed without them, and it would probably not have started either. Both of them have been (and still are) a great example of what a professional, passionate, and hard worker physicist should be.

I am very grateful to the referees of the thesis Dr. Maarten Boonekamp, Prof. Claudio Campagnari and Dr. Mauro Donegà, and the members of my thesis jury Prof. Matteo Cacciari, Dr. Fabrice Hubaut, Dr. Lydia Iconomidou-Fayard, Prof. Shahram Rahatlou, and Prof. Dan Tovey for their comments and suggestions, which help me to significantly improve the quality of this manuscript.

Thanks to the colleagues of the ATLAS *SUSY+Photon* team. Among them, Prof. Bruce Schumm deserves a special mention for his dedication to coordinate the di-photon analysis.

The work presented in this manuscript would not have been possible without the contribution and the support of several people from the *HGamma* and the *E/gamma* ATLAS groups. A special thanks go to Dr. Ruggero Turra for all the inspiring discussions that we had.

Thanks also to the ATLAS *Liquid Argon* group, which is a clear example of fruitful collaboration between expert physicists and committed young students. I have really enjoyed working within the LAr operation team.

Thanks to the ATLAS groups of Milan and Paris for having welcomed me in the past 3 years. I am particularly grateful to my Ph.D. colleagues, with whom I shared very nice experiences, both for work and for leisure.

I then want to thank my family and friends. I have always felt you all hold me in high regard, maybe undeservedly. Your warm support has been always important for me.

Last, but not least, I want to thank Cristina, for keeping up with me in the last 3 years (and the ones before!). You had a very direct experience of pros and cons of a particle physicist's life. I do promise that in the future I will sleep more and disrupt a smaller share of your weekends.

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