

Particle Physics Research Centre
School of Physics and Astronomy
Queen Mary University of London

Measurements of $H \rightarrow b\bar{b}$ decays and VH production

Thomas Charman

Supervisor: Dr. Jonathan Hays

Submitted in partial fulfillment of the requirements of the Degree of Doctor of
Philosophy May 18, 2020.

I, Thomas Paul Charman, confirm that the research included within this thesis is my own work or that where it has been carried out in collaboration with, or supported by others, that this is duly acknowledged below and my contribution indicated. Previously published material is also acknowledged below.

I attest that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge break any UK law, infringe any third party's copyright or other Intellectual Property Right, or contain any confidential material.

I accept that the College has the right to use plagiarism detection software to check the electronic version of the thesis. I confirm that this thesis has not been previously submitted for the award of a degree by this or any other university.

The copyright of this thesis rests with the author and no quotation from it or information derived from it may be published without the prior written consent of the author.

Signature:

Date:

Details of collaboration and publications:

Contents

List of Figures	3
List of Tables	3
1 Introduction	4
Bibliography	6

List of Figures

List of Tables

Chapter 1

Introduction

In 2012 the Higgs boson was discovered by the ATLAS and CMS collaborations at the Large Hadron Collider [1, 2]. It was said to form the last piece of the Standard Model of Particle Physics, a framework that describes three of the four fundamental forces of nature, described in more detail in Chapter ???. Despite apparent completeness after the Higgs discovery, it is known that the theory does not describe gravity, the fourth of the known fundamental forces of nature. The theory also has other shortcomings, it cannot explain the presence of dark matter [3–13] or a number of other observed phenomena [14–18]. So far the model has stood up to all experimental tests [19, 20] concerning its own predictions but there are still parameters of the model that have not been measured. Given the theory’s understood shortcomings, it is hoped that continued scrutiny of the models predictions will yield unexpected results, perhaps hinting at a new way forwards in terms of a theory that describes everything or simply exposing further gaps in our knowledge of the universe. For this reason it is more important than ever to study in detail the most recently discovered piece of the model, the Higgs boson.

This work focuses on studying a specific production mechanism and decay mode of the Higgs boson, specifically a vector boson associated Higgs boson decaying to two bottom quarks, denoted $VH(bb)$. This decay mode is of importance as it is currently the only decay mode of the Higgs decaying to quarks that has been observed [21]. A summary of the full spectrum of production mechanisms and decay modes of the

Higgs will be given in Chapter ??.

The study of this decay mode was carried out with the ATLAS detector, and made possible by the hard work of all members of the ATLAS collaboration. In Chapter ?? the detector is described in full.

Bibliography

- [1] Georges Aad et al. (ATLAS Collaboration). Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC. *Phys. Lett.*, B716:1–29, 2012. doi: 10.1016/j.physletb.2012.08.020.
- [2] Serguei Chatrchyan et al. (CMS Collaboration). Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC. *Phys. Lett.*, B716: 30–61, 2012. doi: 10.1016/j.physletb.2012.08.021.
- [3] Will J. Percival, Shaun Cole, Daniel J. Eisenstein, Robert C. Nichol, John A. Peacock, Adrian C. Pope, and Alexander S. Szalay. Measuring the baryon acoustic oscillation scale using the sloan digital sky survey and 2df galaxy redshift survey. *Monthly Notices of the Royal Astronomical Society*, 381(3): 1053–1066, 2007. doi: 10.1111/j.1365-2966.2007.12268.x. URL <http://dx.doi.org/10.1111/j.1365-2966.2007.12268.x>.
- [4] Fabio Iocco, Gianpiero Mangano, Gennaro Miele, Ofelia Pisanti, and Pasquale D. Serpico. Primordial Nucleosynthesis: from precision cosmology to fundamental physics. *Phys. Rept.*, 472:1–76, 2009. doi: 10.1016/j.physrep.2009.02.002.
- [5] M. Kowalski et al. Improved Cosmological Constraints from New, Old and Combined Supernova Datasets. *Astrophys. J.*, 686:749–778, 2008. doi: 10.1086/589937.
- [6] Richard Massey et al. Dark matter maps reveal cosmic scaffolding. *Nature*, 445:286, 2007. doi: 10.1038/nature05497.

- [7] Douglas Clowe, Marusa Bradac, Anthony H. Gonzalez, Maxim Markevitch, Scott W. Randall, Christine Jones, and Dennis Zaritsky. A direct empirical proof of the existence of dark matter. *Astrophys. J.*, 648:L109–L113, 2006. doi: 10.1086/508162.
- [8] J. Anthony Tyson, Greg P. Kochanski, and Ian P. Dell’Antonio. Detailed mass map of CL0024+1654 from strong lensing. *Astrophys. J.*, 498:L107, 1998. doi: 10.1086/311314.
- [9] Lars Bergstrom. Dark Matter Candidates. *New J. Phys.*, 11:105006, 2009. doi: 10.1088/1367-2630/11/10/105006.
- [10] C. Patrignani et al. Review of Particle Physics. *Chin. Phys.*, C40(10):100001, 2016. doi: 10.1088/1674-1137/40/10/100001.
- [11] F. Zwicky. Republication of: The redshift of extragalactic nebulae. *General Relativity and Gravitation*, 41:207–224, January 2009. doi: 10.1007/s10714-008-0707-4.
- [12] Lars Bergström. Nonbaryonic dark matter: Observational evidence and detection methods. *Rept. Prog. Phys.*, 63:793, 2000. doi: 10.1088/0034-4885/63/5/2r3.
- [13] Gianfranco Bertone, Dan Hooper, and Joseph Silk. Particle dark matter: Evidence, candidates and constraints. *Phys. Rept.*, 405:279–390, 2005. doi: 10.1016/j.physrep.2004.08.031.
- [14] Roel Aaij et al. Measurement of the ratio of branching fractions $\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\tau^-\bar{\nu}_\tau)/\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\mu^-\bar{\nu}_\mu)$. *Phys. Rev. Lett.*, 115(11):111803, 2015. doi: 10.1103/PhysRevLett.115.159901, 10.1103/PhysRevLett.115.111803. [Erratum: *Phys. Rev. Lett.* 115, no. 15, 159901 (2015)].
- [15] J. P. Lees et al. Evidence for an excess of $\bar{B} \rightarrow D^{(*)}\tau^-\bar{\nu}_\tau$ decays. *Phys. Rev. Lett.*, 109:101802, 2012. doi: 10.1103/PhysRevLett.109.101802.

- [16] Thomas Blum, Achim Denig, Ivan Logashenko, Eduardo de Rafael, B. Lee Roberts, Thomas Teubner, and Graziano Venanzoni. The Muon ($g-2$) Theory Value: Present and Future. 2013.
- [17] Carl E. Carlson. The Proton Radius Puzzle. *Prog. Part. Nucl. Phys.*, 82:59–77, 2015. doi: 10.1016/j.pnpnp.2015.01.002.
- [18] Bernat Capdevila, Andreas Crivellin, Sébastien Descotes-Genon, Joaquim Matias, and Javier Virto. Patterns of New Physics in $b \rightarrow s\ell^+\ell^-$ transitions in the light of recent data. *JHEP*, 01:093, 2018. doi: 10.1007/JHEP01(2018)093.
- [19] John D. Hobbs, Mark S. Neubauer, and Scott Willenbrock. Tests of the standard electroweak model at the energy frontier. *Rev. Mod. Phys.*, 84: 1477–1526, Oct 2012. doi: 10.1103/RevModPhys.84.1477. URL <https://link.aps.org/doi/10.1103/RevModPhys.84.1477>.
- [20] L. Nodulman. Experimental tests of the standard model. *NATO Sci. Ser. C*, 534:147–193, 1999. doi: 10.1007/978-94-011-4689-0_4.
- [21] Morad Aaboud et al. Observation of $H \rightarrow b\bar{b}$ decays and VH production with the ATLAS detector. *Phys. Lett.*, B786:59–86, 2018. doi: 10.1016/j.physletb.2018.09.013.