Preface

The nature of DM remains one of the greatest mysteries in modern physics, despite being significantly more abundant than the normal matter with which everyone is familiar. One method to probe DM is by watching for its production in high energy collisions, such as by the ATLAS experiment at the LHC. The mono-jet search is a particularly powerful way of studying such DM production at the LHC, and is the primary focus of this thesis.

This thesis begins by considering the motivation for DM as a whole, the WIMP interpretation thereof, and existing searches for DM, as detailed in Chap. 1. The focus then shifts to the ATLAS experiment, beginning with a description of the detector in Chap. 2 and general physics object reconstruction and performance in Chap. 3. A specific focus is then placed on one of the most important performance aspects of the mono-jet analysis, jets, in Chaps. 4 and 5. The core of the mono-jet analysis is discussed in Chap. 6, while the interpretation of the analysis as a search for DM is contained in Chap. 7. The thesis ends with an outlook on the possible sensitivity of the analysis under future LHC conditions in Chap. 8 and an overall conclusion in Chap. 9.

Experimental particle physics has evolved into a field which requires very intricate detectors and complicated research questions, where no one person can contribute to every aspect of the experiment. The ATLAS Collaboration is comprised of approximately 3000 members from across the world who have all contributed. This involves building detector components, monitoring the detector operation, translating detector signals into physics information, deriving calibrations, managing the computing resources, and any number of other tasks. In reality, any individual study relies on a significant amount of work done by other people, thus the full ATLAS author list is appended to all ATLAS publications.

Similarly, this document cannot exist in isolation, as it involves both direct and indirect contributions from many individuals. Major contributions of the author within this document are listed below.

Chapter 3: ATLAS Reconstruction and Performance

The author contributed to the treatment of missing transverse momentum in ATLAS. This includes updating the reconstruction software and investigating possible cleaning criteria for the rejection of events with large amounts of fake missing transverse momentum from improperly reconstructed muons.

Chapter 4: Jet Reconstruction and Performance

The author was involved in the development and implementation of jet reconstruction software, both during Run-I activities and in preparation for Run-II. The author also contributed to the validation of jet reconstruction and associated property calculations.

The author made several small contributions to the jet calibration procedure as a whole, with a particular emphasis on corrections for jets which are not contained within the ATLAS calorimetry. The technical details of the full calibration procedure and the specific correction for non-contained jets are provided in Sects. 4.2 and 4.4 respectively.

The author was one of two principal investigators studying the impact of masked Tile calorimeter regions on the performance of jets, and was responsible for determining the optimal cleaning cut criteria. The author also wrote the associated software package for general use, and was the principal contact for the full ATLAS experiment in matters relating to jet performance around these masked regions. The technical studies that went into the creation of the cleaning selection are provided in Sect. 4.6.

Chapter 5: Jet Uncertainties

The author was the primary contact, developer, and maintainer of all aspects of the systematic uncertainties associated with the jet energy scale. This covers a large number of contributions, including (but not limited to) the creation of software tools to facilitate ease of access to the uncertainties, eigen decompositions of the uncertainties to create a more accessible format, and the creation of alternative correlation scenarios to quantify the assumptions which went into the derivation of the uncertainties. All of these concepts are thoroughly documented in this chapter.

Chapter 6: The Mono-jet Analysis

The author contributed to many different aspects of the mono-jet analysis from the start to the end of the process. The author regularly provided input and feedback on all stages of the analysis, and provided cross-checks to the main result through the independent data-driven estimation of the dominant $Z \to \nu\nu$ + jets and W $\to l\nu$ +

jets backgrounds, with a focus on the muon control regions. The author was also responsible for deriving the diboson normalization uncertainties.

In addition to these purely analysis-related contributions, the author also significantly improved performance-related aspects of the analysis. This includes optimization of the jet-related uncertainties, studies on the impact of punch-through jets, cleaning cuts for jets near masked Tile calorimeter modules, and optimization of the missing transverse momentum variation to use for the analysis.

Chapter 7: Mono-jet Dark Matter Interpretation

The author has contributed to essentially every aspect of the mono-jet Dark Matter (DM) interpretation. The author was solely responsible for the production of all of the DM signal samples, both for this analysis [1], the previous iteration of the analysis [2], and an analysis with a different but related topology [3]. This includes both the production of central values for typical analysis use and the production of samples with the variations required for the derivation of systematic uncertainties associated with the signal models. The production and validation of DM signal samples and associated systematic uncertainty derivations is provided in Appendix B due to its very technical nature.

The author was also the primary signal validation expert, contributed towards the evaluation of systematic uncertainties, and was jointly responsible for the calculation of limits for all of the DM models with an emphasis on the effective field theory samples.

The author led the ATLAS effort to understand the experimental implications of the validity of DM effective field theory models at the LHC, initially investigated for one scenario in ATL-PHYS-PUB-2014-007, fully studied in Ref. [1], and now utilized by multiple other ATLAS searches such as Refs. [3, 4]. Despite being a significant example of the author's contributions, the studies are very technical, and thus they are documented in Appendix A.

Chapter 8: Mono-jet Prospects at an Upgraded LHC

The author is one of four principal analyzers in Ref. [4], and thus was partially involved in most stages of the analysis. The author was solely responsible for the investigation of the impact of increased pileup conditions on jet performance as well as the aforementioned preliminary studies into effective field theory validity criteria. Beyond these two responsibilities, the author also contributed to the DM limit derivations for use in the sensitivity studies.

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