

Shining Light on Dark Matter, One Photon at a Time

by

Brandon Leigh Allen

Submitted to the Department of Physics
in partial fulfillment of the requirements for the degree of

Doctorate of Science in Physics

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2019

© Massachusetts Institute of Technology 2019. All rights reserved.

Author

Department of Physics

May 18, 2019

Certified by

Christoph E.M. Paus

Professor

Thesis Supervisor

Accepted by

Arthur C. Smith

Chairman, Department Committee on Graduate Theses

Shining Light on Dark Matter, One Photon at a Time

by

Brandon Leigh Allen

Submitted to the Department of Physics
on May 18, 2019, in partial fulfillment of the
requirements for the degree of
Doctorate of Science in Physics

Abstract

A search is conducted for new physics in final states containing a photon and missing transverse momentum in proton-proton collisions at $\sqrt{s} = 13$ TeV. The data collected by the CMS experiment at the CERN LHC correspond to an integrated luminosity of 35.9 inverse femtobarns. The results are interpreted as exclusion limits on the various dark matter models, such as heavy vector mediators, dimension-7 contact operators, and Higgs-portal dark sectors. Improved limits are set with respect to previous analyses using photon plus missing transverse momentum final states.

Thesis Supervisor: Christoph E.M. Paus

Title: Professor

Acknowledgments

This is the acknowledgements section. You should replace this with your own acknowledgements.

Contents

1	Introduction	13
2	Motivation	15
2.1	Astrophysical Evidence for Dark Matter	15
2.2	Simplified Models for the WIMP Paradigm	15
3	The CMS Detector	17
3.1	Detector Overview	17
3.1.1	Silicon Pixel Detector	17
3.1.2	Silicon Strip Tracker	17
3.1.3	Electromagnetic Calorimeter	17
3.1.4	Hadronic Calorimeter	17
3.1.5	Muon Detectors	18
4	Reconstruction	19
4.1	Reconstruction	19
4.1.1	Particle Flow	19
4.1.2	MET Reconstruction	19
4.2	Calibration	19
4.2.1	Trigger Efficiency	20
4.2.2	Photon Scale Factor	20
4.2.3	Pixel Veto Scale Factor	20
4.2.4	Lepton Scale Factors	20

4.2.5	Jet Energy Scale	20
4.3	Non-collision signatures	20
4.3.1	Beam halo	20
4.3.2	ECAL Spikes	20
4.3.3	Fake MET	20
5	The Monophoton Analysis	21
5.1	Event Selection	22
5.2	Irreducible backgrounds	22
5.3	Misidentified backgrounds	22
5.3.1	Electrons	22
5.3.2	Hadrons	22
5.4	Non-collision backgrounds	22
5.4.1	Spikes	22
5.4.2	Beam halo	22
5.5	Statistical Interpretation	22
5.6	Results	22
6	Comparison with Other Results	23
6.1	Monophoton	23
6.2	Monojet / Mono- Z	23
6.3	Direct Detection	23
6.4	Indirect Detection	23
7	Conclusion	25

List of Figures

List of Tables

Chapter 1

Introduction

Things to be introduced.

Chapter 2

Motivation

Why I did this.

2.1 Astrophysical Evidence for Dark Matter

Galactic Rotation Curves and the Bullet Cluster.

2.2 Simplified Models for the WIMP Paradigm

It was the hot thing at the time.

Chapter 3

The CMS Detector

The big thing we know and love.

3.1 Detector Overview

What are the parts.

3.1.1 Silicon Pixel Detector

The tiny dots.

3.1.2 Silicon Strip Tracker

The thin strips.

3.1.3 Electromagnetic Calorimeter

Our PbWO_4 guys.

3.1.4 Hadronic Calorimeter

Our big brassy boi.

3.1.5 Muon Detectors

The red ones.

Chapter 4

Reconstruction

4.1 Reconstruction

How do we turn electrical signals into physics.

4.1.1 Particle Flow

4.1.2 MET Reconstruction

4.2 Calibration

How good is the reconstruction.

4.2.1 Trigger Efficiency

4.2.2 Photon Scale Factor

4.2.3 Pixel Veto Scale Factor

4.2.4 Lepton Scale Factors

4.2.5 Jet Energy Scale

4.3 Non-collision signatures

Things that don't come from protons.

4.3.1 Beam halo

4.3.2 ECAL Spikes

4.3.3 Fake MET

Chapter 5

The Monophoton Analysis

The main event.

- 5.1 Event Selection
- 5.2 Irreducible backgrounds
- 5.3 Misidentified backgrounds
 - 5.3.1 Electrons
 - 5.3.2 Hadrons
- 5.4 Non-collision backgrounds
 - 5.4.1 Spikes
 - 5.4.2 Beam halo
- 5.5 Statistical Interpretation
- 5.6 Results

Chapter 6

Comparison with Other Results

We're not doing this in a vacuum.

6.1 Monophoton

6.2 Monojet / Mono- Z

6.3 Direct Detection

6.4 Indirect Detection

Chapter 7

Conclusion

Things to conclude.