A Measurement of $Z(\nu\bar{\nu})\gamma$ Production and a Search for New Physics in Monophoton Events Using the CMS Detector at the LHC

by

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Abstract

This thesis presents several studies of monophoton final states using 35.9 fb^{-1} of 13 TeV proton-proton collision data collected by the CMS experiment at the LHC in 2016. The standard model $Z(\nu\bar{\nu})\gamma$ cross section is measured as a function of photon transverse momentum. No significant deviations from standard model predictions are observed. The results are also interpreted in the context of several new physics models. Limits are placed on coupling strengths of anomalous triple gauge couplings between photons and Z bosons, new particle masses in simplified models of dark matter, the suppression scale of a dark matter effective field theory model, and the graviton mass scale in a model of extra spatial dimensions.

Chapter 1

Introduction

1.1 Overview

This thesis presents several analyses of event yields in "monophoton" final states, characterized by a single γ with high transverse momentum, along with an overall transverse momentum imbalance typically of equal magnitude and opposite direction to that of the photon. These analyses correspond to 35.9 fb^{-1} of 13 TeV proton-proton (pp) collision data collected in 2016 by the CMS detector at the LHC. A measurement of the production rate for the process $pp \to Z\gamma \to \nu\bar{\nu}\gamma$ is obtained and compared to predictions derived from the standard model (SM) of particle physics. No significant deviation from SM predictions is observed.

The predicted monophoton yield in several theories of physics beyond the SM (BSM) is higher than the SM prediction. This thesis examines two varieties of anomalous triple gauge coupling (aTGC), simplified models of dark matter (DM) interacting with SM matter via a vector or axial-vector mediator, an effective field theory (EFT) of DM interaction with γ and Z bosons, and a model of extra spatial dimensions. For each of these models, 95% confidence level (CL) limits are placed on relevant parameters based on the observed collision data.

1.2 Standard model of particle physics

Introduce basic SM concepts and vocabulary.

1.3 $Z(\nu\bar{\nu})\gamma$ cross section

Introduce the $Z(\nu\bar{\nu})\gamma$ process and discuss its cross section. Include a discussion of NNLO QCD and NLO EWK corrections.

Previous measurements

List previous experimental work constraining the $Z(\nu\bar{\nu})\gamma$ cross section.

1.4 Anomalous triple gauge couplings

Introduce the effective vertex model that parametrizes our aTGC limits.

Previous searches

List previous experimental work constraining the Z-γ aTGC parameters via the study of $Z\gamma$ processes.

1.5 Dark matter simplified models

A brief introduction to DM followed by an introduction to the DM simplified models with a vector and axial-vector mediator, as well as the EWK EFT model describing a direct DM-EWK boson interaction.

Previous searches

List previous experimental work constraining the model parameters, with a focus on the monophoton channel.

1.6 ADD gravitons

Introduce the ADD extra dimensions model and the phenomenological signature of ADD graviton emission.

Previous searches

List previous experimental work constraining ADD model parameters, with a focus on the monophoton channel.

Chapter 2

The CMS experiment and the LHC

2.1 The LHC

Proton acceleration

Magnets and beam halo

Beam halo is an important component of the monophoton analysis and it comes from here.

2.2 The CMS experiment

Coordinate system

Superconducting solenoid and silicon tracking system

Electromagnetic calorimeter

The discussion of APDs segues into an introduction to ECAL spikes.

Hadronic calorimeter

Muon systems

Trigger system

Chapter 3

Simulation

3.1 Hard process generation

3.2 Parton distribution functions

3.3 Parton showering and hadronization

3.4 Pileup simulation

3.5 Detector simulation

Chapter 4

Object reconstruction and selection

4.1 The particle-flow algorithm

4.2 Photons and electrons

4.3 Muons

4.4 Jets and missing transverse momentum

A discussion of jets is followed by a definition of $p_{\mathrm{T}}^{\mathrm{miss}}$ and Type-1 $p_{\mathrm{T}}^{\mathrm{miss}}$ corrections.

4.5 Primary vertex

Chapter 5

Event selection

5.1 Backgrounds

List the sources of background in the monophoton channel, to justify the ensuing cuts.

5.2 Trigger and $p_{\mathrm{T}}^{\mathrm{miss}}$ filters

Trigger path, trigger efficiency

$p_{\mathrm{T}}^{\mathrm{miss}}$ filters

5.3 Photon

Photon kinematic cuts; Photon ID defintion, efficiency; Spike and beam halo cuts; phoET-dependent cross section corrections

5.4 Missing transverse momentum

$p_{\mathrm{T}}^{\mathrm{miss}} > 170$ GeV; $\Delta\phi(\gamma, \vec{p}_{\mathrm{T}}^{\mathrm{miss}}) > 0.5$; $\mathrm{min}\Delta\phi(\mathrm{jets}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}}) > 0.5$; $E_{\mathrm{T}}^{\gamma}/p_{\mathrm{T}}^{\mathrm{miss}} < 1.4$

5.5 Lepton vetoes

Electron selection; Muon selection

5.6 Single electron control region

5.7 Single muon control region

5.8 Dielectron control region

5.9 Dimuon control region

Chapter 6

Background estimation

For each component, describe its estimation and uncertainties

6.1 Simulated backgrounds

6.2 Electron faking photon

6.3 Jet faking photon

6.4 Spikes

6.5 Beam halo

6.6 Transfer factors

6.7 Likelihood function

Chapter 7

Results

7.1 $Z(\nu\bar{\nu})\gamma$ cross section

7.2 aTGC limits

7.3 DM simplified model limits

7.4 ADD limits

Chapter 8

Conclusions

8.1 Summary

8.2 Outlook