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# Search for diboson resonances with CMS and Optimization and Upgrade of the CMS Pixel Barrel Detector

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Dissertation

zur

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# Introduction

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# The CMS Experiment at the LHC

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## 2.1 The Large Hadron Collider

## 2.2 The CMS Detector

### 2.2.1 The Silicon Tracker

### 2.2.2 The Electromagnetic Calorimeter

### 2.2.3 The Hadronic Calorimeter

### 2.2.4 The Muon System

### 2.2.5 The Trigger System

## Part I

# Search for diboson resonances with CMS

# The Standard Model and beyond

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## 3.1 The Standard Model

### 3.1.1 Particles and interactions

### 3.1.2 Spontaneous symmetry breaking

### 3.1.3 The Higgs mechanism

### 3.1.4 The Higgs boson discovery at LHC

## 3.2 The hierarchy problem and other SM limitations

## 3.3 Theories of new physics

### 3.3.1 Warped Extra dimensions

### 3.3.2 Compositeness

### 3.3.3 Heavy vector triplet

## 3.4 Diboson resonances as signature for new physics



# Object and event reconstruction

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## 4.1 Tracks and vertices

## 4.2 Electrons

## 4.3 Muons

## 4.4 Jets

### 4.4.1 Identification of b jets

## 4.5 Missing transverse energy

# Dataset and event simulation

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5.1 Datasets at  $\sqrt{s} = 8$  and 13 TeV

5.2 Monte Carlo event generators

5.3 The CMS detector simulation

5.4 Simulation of physics processes

5.4.1 Simulation of signal processes

5.4.2 Simulation of background processes

# Boosted $H \rightarrow b\bar{b}$ and $W/Z \rightarrow q\bar{q}^{(\prime)}$ identification with jet substructure

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## 6.1 Jet substructure algorithms

### 6.1.1 Jet pruning

### 6.1.2 N-subjettiness

## 6.2 W/Z-tagging validation in top enriched sample

## 6.3 H-tagging algorithm

# Final event selection and categorization

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## 7.1 $W \rightarrow \ell \nu$ reconstruction

## 7.2 Search for a WH resonance in the $\ell \nu b \bar{b}$ final state at $\sqrt{s} = 8$ TeV

### 7.2.1 $t\bar{t}$ background rejection

### 7.2.2 Final selection and control plots

## 7.3 Search for WW/WZ resonances in the $\ell \nu q \bar{q}^{(\prime)}$ final state at $\sqrt{s} = 13$ TeV

### 7.3.1 W/Z-jet mass categories

### 7.3.2 Final selection and control plots

# Signal and background modeling

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## 8.1 Signal modeling

### 8.1.1 Parametrization of the resonance mass

### 8.1.2 Signal efficiency

## 8.2 Background modeling

### 8.2.1 W+jets background estimate with alpha method

### 8.2.2 $t\bar{t}$ control sample

## 8.3 Systematic uncertainties

### 8.3.1 Systematic uncertainties in the background estimation

### 8.3.2 Systematic uncertainties in the signal prediction

# Final results and statistical treatment

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## 9.1 Testing new resonance hypothesis

### 9.1.1 Profile likelihood procedure

### 9.1.2 The $CL_s$ method

### 9.1.3 Treatment of uncertainties

## 9.2 Results with 8 TeV data

### 9.2.1 Final $m_{WH}$ distribution

### 9.2.2 Studies on the excess

### 9.2.3 Statistical and model interpretation

## 9.3 Results with 13 TeV data

### 9.3.1 Final $m_{WV}$ distribution

### 9.3.2 Statistical and model interpretation

# Combination of searches for diboson resonances at $\sqrt{s} = 8$ and 13 TeV

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## 10.1 Inputs to the combination

### 10.1.1 8 TeV VV searches

### 10.1.2 13 TeV VV searches

### 10.1.3 8 TeV VH searches

### 10.1.4 13 TeV VH searches

## 10.2 Combination procedure

## 10.3 Results

### 10.3.1 Limits on $W'$

### 10.3.2 Limits on $Z'$

### 10.3.3 Limits on heavy vector triplet ( $W'+Z'$ )

### 10.3.4 Limits on Bulk Graviton

### 10.3.5 Significance at 2 TeV

## **Part II**

# **Optimization and Upgrade of the CMS Pixel Barrel Detector**



# The CMS Pixel Barrel Detector

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## 11.1 Design of the CMS Pixel Barrel Detector

## 11.2 Detector modules

### 11.2.1 Sensor

### 11.2.2 Readout Chip

### 11.2.3 Token Bit Manager

## 11.3 Readout and control system

### 11.3.1 Analog readout chain

### 11.3.2 Front End Driver

### 11.3.3 Supply Tube

### 11.3.4 Communication and Control Unit

### 11.3.5 Front End Controller

## 11.4 Pixel Online Software

# Optimization and commissioning for LHC Run II

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## 12.1 Radiation damage after LHC Run I

## 12.2 Optimization for LHC Run II

### 12.2.1 Overview of pixel calibrations

### 12.2.2 Temperature dependence

## 12.3 Commissioning for LHC Run II

### 12.3.1 Installation into CMS

### 12.3.2 Check out of optical connections

### 12.3.3 Adjustment of readout chain settings

### 12.3.4 Optimisation of signal performance

# Phase I Upgrade of the CMS Pixel Barrel Detector

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13.1 Motivations

13.2 Summary of changes

13.3 The digital readout chain

13.4 The Phase I supply tubes

13.5 The test stand

13.6 Supply tubes assembly and commissioning

13.7 Detector commissioning