

**Search For A Standard Model Higgs Boson
Produced In The Decay Channel $H \rightarrow \gamma\gamma$
with CMS Detector**

Thesis submitted for the degree of
Doctor of Philosophy (Science)
in
Physics

by
Swagata Mukherjee

Department of Physics
University of Calcutta

2015

CONTENTS

Acknowledgements	iii
List of publications	v
List of figures	ix
List of tables	xiii
1 Introduction	1
2 Theory and Statistical Tools	5
2.1 The Standard Model of particle physics in brief	5
2.1.1 The Strong Sector	5
2.1.2 The Electroweak Sector	7
2.1.3 The Higgs Sector and Spontaneous Symmetry Breaking	9
2.1.4 Production of SM Higgs Boson	12
2.1.5 Decay of SM Higgs Boson	15
2.2 Beyond the Standard Model	17
2.2.1 Extra Dimension	18
2.2.2 Effective Lagrangian	18
2.3 Statistical Methods for Higgs Analyses	20
2.3.1 Statistical Test	20
2.3.2 Multivariate Analysis (MVA) Techniques	23
2.4 Summary	25
3 The Experimental Setup	26
3.1 The Large Hadron Collider	26
3.2 The Compact Muon Solenoid	28
3.2.1 Solenoidal Magnet	30
3.2.2 Inner Tracker	30

3.2.3	Electromagnetic Calorimeter	31
3.2.4	Hadron Calorimeter	32
3.2.5	Muon System	34
3.2.6	Trigger and Data Acquisition System	35
3.3	HCAL Upgrade	37
3.3.1	HCAL Back End Electronics	39
3.4	Summary	43
4	Particle Flow in CMS	44
4.1	CMS Particle Flow Algorithm	44
4.2	Inclusion of Hadron Outer Calorimeter in Particle Flow Calibration	45
4.2.1	Particle flow calibration without HO	46
4.2.2	Particle flow calibration with HO	48
4.2.3	Energy resolution after inclusion of HO in PF calibration	51
4.2.4	Performance of HO with jets	52
4.2.5	Calibration of HO using jets	53
4.3	Summary	54
5	Object Reconstruction and Event Simulation	56
5.1	Energy measurement in ECAL	56
5.2	Photon Reconstruction and Photon Energy Correction	57
5.2.1	Calibration of ECAL channels	57
5.2.2	Clustering	57
5.2.3	Correction of cluster energy using multivariate regression technique	59
5.2.4	Residual Photon Energy Scale and Resolution Corrections	61
5.2.5	Photon Energy Resolution	62
5.3	Photon Conversions	62
5.3.1	Conversion Reconstruction	63
5.4	Electron Reconstruction	64
5.5	Primary Vertex Reconstruction	66
5.6	Jet reconstruction	66
5.6.1	Jet Algorithms	67
5.6.2	Jet Energy Resolution	68
5.7	Monte Carlo Simulation	68
5.8	Summary	70
6	Measurement of $H \rightarrow \gamma\gamma$ differential cross-sections	71
6.1	Data and Simulation	71
6.2	Trigger Criteria	73
6.3	Selection of Primary Vertex	73

6.4	Selection of Photons	76
6.5	Selection of Jets	80
6.6	Event Classification	81
6.7	Observables	83
6.8	Binning	85
6.9	Statistical Analysis	85
6.9.1	Unfolding and Result Extraction	89
6.10	Systematic Uncertainties	91
6.11	Results and Comparison with Theoretical Predictions	93
6.11.1	Fiducial Cross-Section	95
6.11.2	Differential Cross-Sections	95
6.12	Summary	101
7	$H \rightarrow \gamma\gamma$ Upgrade Studies for HL-LHC	102
7.1	Upgrade study strategy and upgrade scenarios	103
7.1.1	Current Analysis Scenario	103
7.1.2	Alternate photon η acceptance scenarios	103
7.1.3	Alternate photon p_T acceptance scenarios	104
7.1.4	Photon transverse momentum resolution scenarios	104
7.2	Detector acceptance in different upgrade scenarios	105
7.2.1	Gluon Fusion	105
7.2.2	Vector Boson Fusion	105
7.2.3	Associated production with a gauge boson	106
7.3	Impact of resolution scenarios on $H \rightarrow \gamma\gamma$ signal line shape	106
7.4	Background rates and signal over background	107
7.5	Expected precision on μ at 14 TeV for 300 fb ⁻¹ and 3000 fb ⁻¹	108
7.6	Summary	110
8	Conclusion and Final Remarks	111
A	Signal strength for different upgrade scenarios	113
B	Plots for Signal Model	115
C	Plots for Background Model	119
	Bibliography	123