Brunel University

Doctoral Thesis

Measurement of the inclusive top-quark pair plus a radiated photon production cross section in the dilepton channel in pp collisions at 8TeV

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A dissertation submitted to Brunel University
in accordance with the requirements
for award of the degree of Doctor of Philosophy

in

the Faculty of Particle Physics
Centre for Sensors & Instrumentation

August 21, 2015

Declaration of Authorship

I, Nik Berry, declare that the work in this dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Research Degree Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

SIGNED: .... DATE: ....

(Signature of student)

“Real courage is when you know you’re licked before you begin, but you begin anyway and see it through no matter what.”

Harper Lee, To Kill a Mockingbird

Abstract

We present the top-quark pair plus photon production cross section measured in pp collisions at a centre-of-mass energy of 8 TeV with the CMS detector at the Large Hadron Collider, using data recorded in 2012 corresponding to an integrated luminosity of Lint = 19.6 fb 1 . The measurement is performed in the dilepton decay channel. The signal region is defined by the final state of the process pp W + W b b, with a minimum photon transverse energy of $\mathrm{E_T}(\gamma) > 20$ GeV and minimum distance of $\Delta R(\gamma, b/\bar{b}) > 0.1$ between the photon and the b-quark in $\eta - \phi$ space. Signal events are simulated using the WHIZARD event generator. The normalized cross- section, $R = \frac{\sigma_{t\bar{t}+\gamma}}{\sigma_{t\bar{t}}}$, is exploited in order to cancel various sources of systematic uncertainties. the largest contribution to the systematic uncertainty of 17.3 arises due to the modelling of the $t\bar{t}$ background process. We measure the fiducial normalised cross-section, requiring $\mathrm{E}_T(\gamma) > 25$ GeV and $\eta(\gamma) < 1.4442$ on the final state photon, to be $R^{fid.} = (0.72 \pm 0.04(stat.) \pm 0.15(syst.)) \times 10^2$. Extrapolated into the signal region, we obtain $R = (0.89 \pm 0.05(stat.) \pm 0.18(syst.)) \times 10^2$. Using a recent CMS $t\bar{t}$ cross-section measurement at 8 TeV, we calculate the top pair plus photon production cross-section to be $\sigma^{CMS}_{t\bar{t}+\gamma} = 2.0 \pm 0.1(stat.) \pm 0.4(syst.)$. Being in agreement with the $t\bar{t}+\gamma$ SM expectation of $\sigma^{SM}_{t\bar{t}+\gamma} = 1.8 \pm 0.5$ pb, this is the most accurate measurement of the $t\bar{t}+\gamma$ process to date, and the first at a center-of-mass energy of 8 TeV.

The acknowledgements and the people to thank go here, don't forget to include your project advisor…

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Introduction

Chapter 1

The LHC and the CMS Detector

1.1 The Large Hadron Collider

The Large HAdron Collider (LHC) is currently the largest, and highest energy, particle accelerator ever created. Located, on avergae, one hundred metres under the Franco-Swiss border at Geneva, the LHC is installed in the 26.7 km tunnel that once contained the Large Electron-Positron Collider (LEP), and ran from 1989 until the end of 2000. The project was approved by the CERN council in December of 1994. Originally, the accelerator was designed as a two-stage project: constructed to run at a centre-of-mass energy of $\sqrt{s} = 7$ TeV, and later an upgrade to $\sqrt{s} = 14$ TeV. This was due to budget constraints which did not include contributions from non memeber states.

After many setbacks, the first run began in 2010 and continued until the end of 2011 when the beam energy was then increased to $\sqrt{s} = 8$ TeV for the whole of 2012 before shifting to Long Shutdown 1 (LS1) from 2013 to 2015. During LS1 the CERN accelerator complex, shown in Figure 1.1, was completely upgraded in order to run at a new unprecedented centre-of-mass energy of $\sqrt{s} = 13$ TeV before ramping up to the original design energy of $\sqrt{s} = 14$ TeV.

1.2 The CMS Detector

1.3 Tracking System

Figure 1.3 schematic cross section through the CMS tracker. Each line represents a detector module. Double lines indicate back-to-back modules which deliver stereo hits [1].

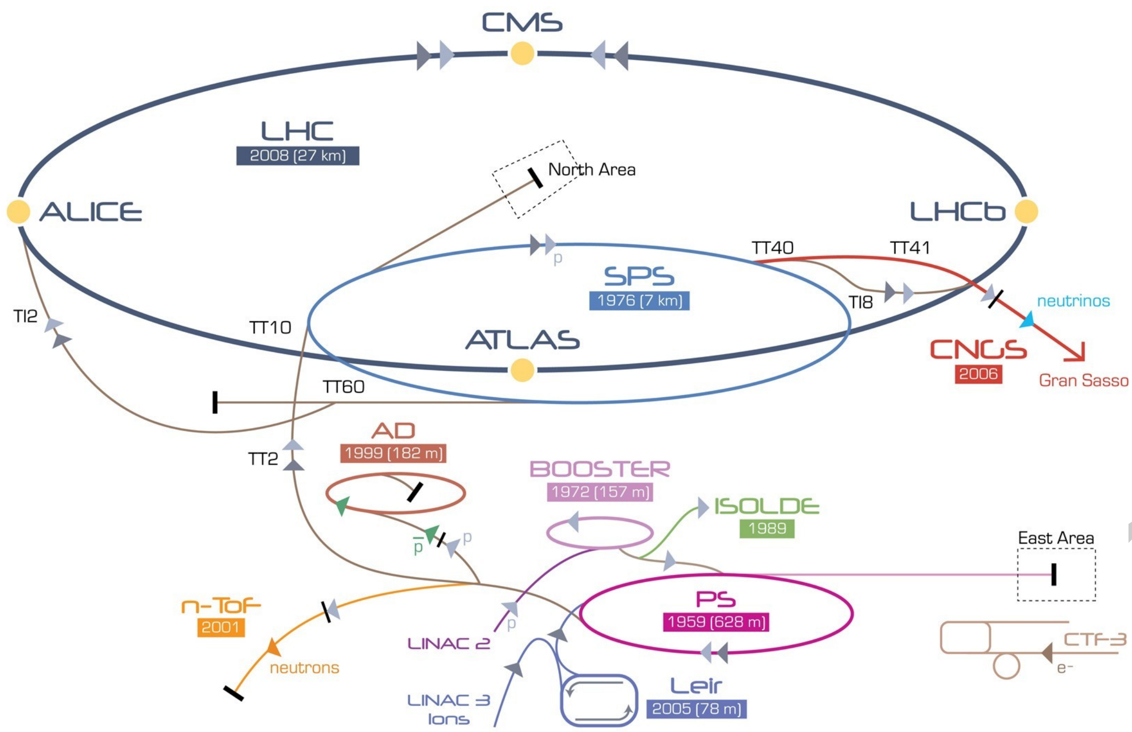

Figure 1.1: A full schematic of the full CERN accelerator complex [].

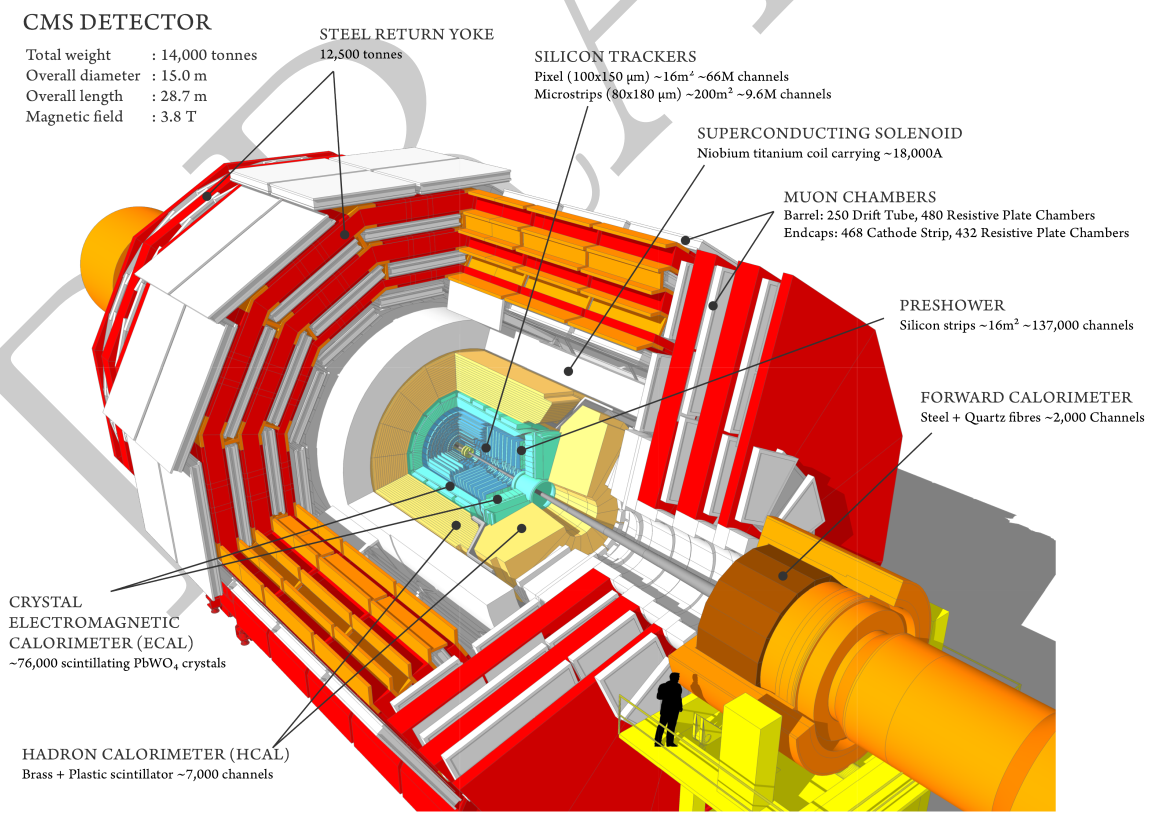

Figure 1.2: A cross-sectional view of the CMS detector [].

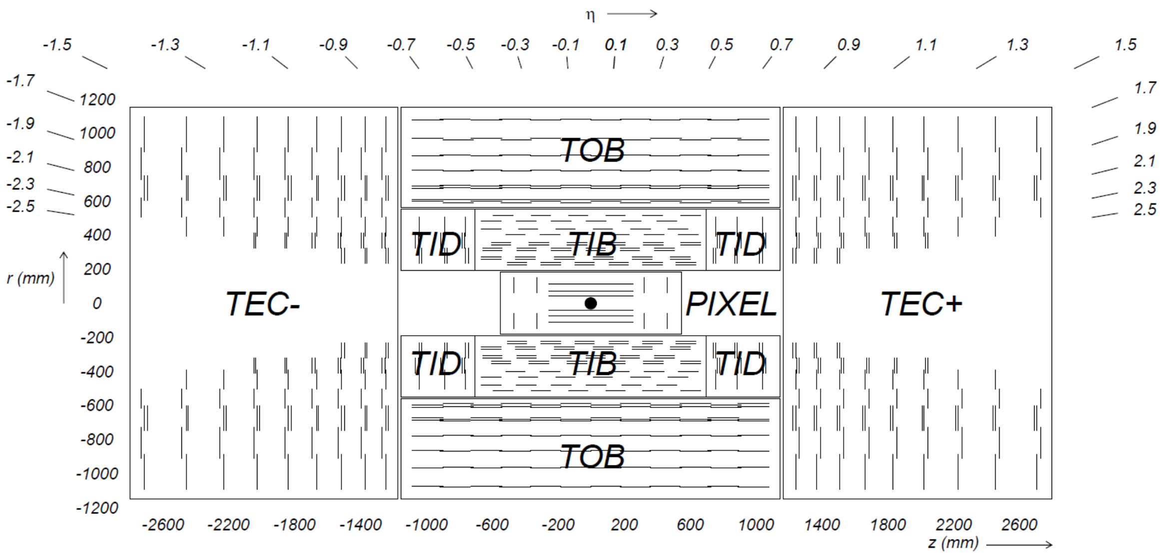

Figure 1.3: The subdetectors of the CMS silicon tracker system: TOB=outer barrel, TIB=inner barrel, TID=inner disc, TEC=endcaps, PIXEL=pixeldetector [].

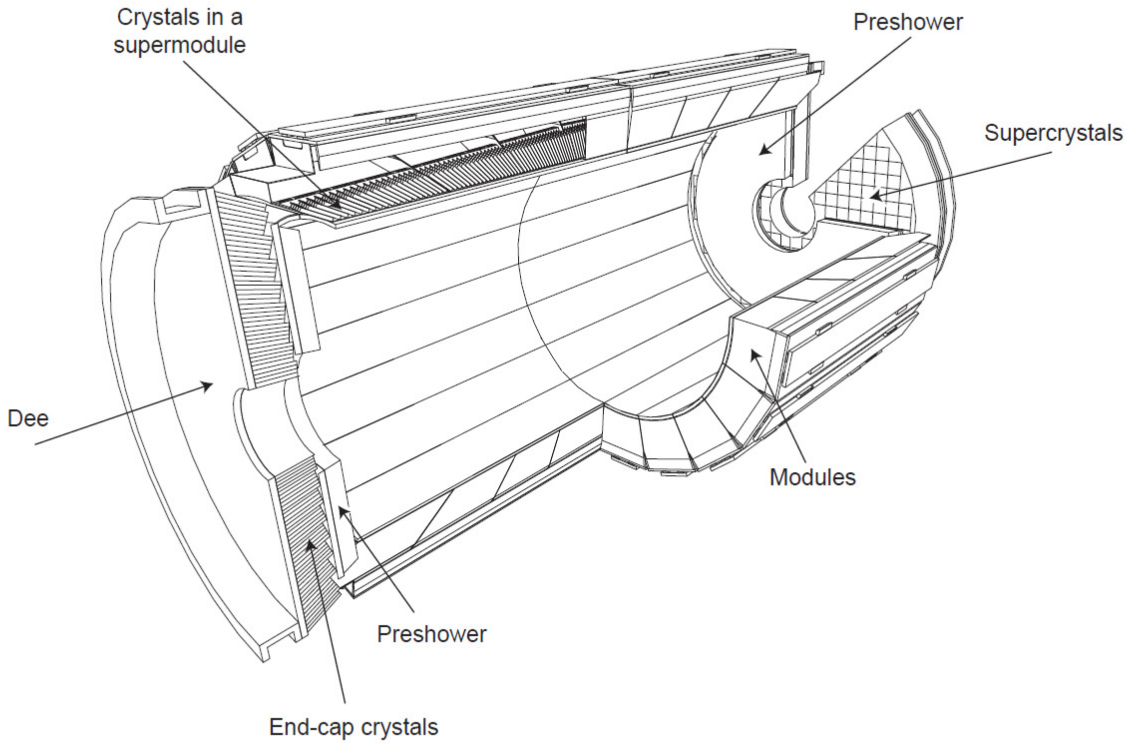

Figure 1.4: Geometric view of one quarter of the ECAL (top). Layout of the CMS electromagnetic calorimeter presenting the arrangement of crystal modules, supermodules, endcaps and the preshower in front (bottom) [1].

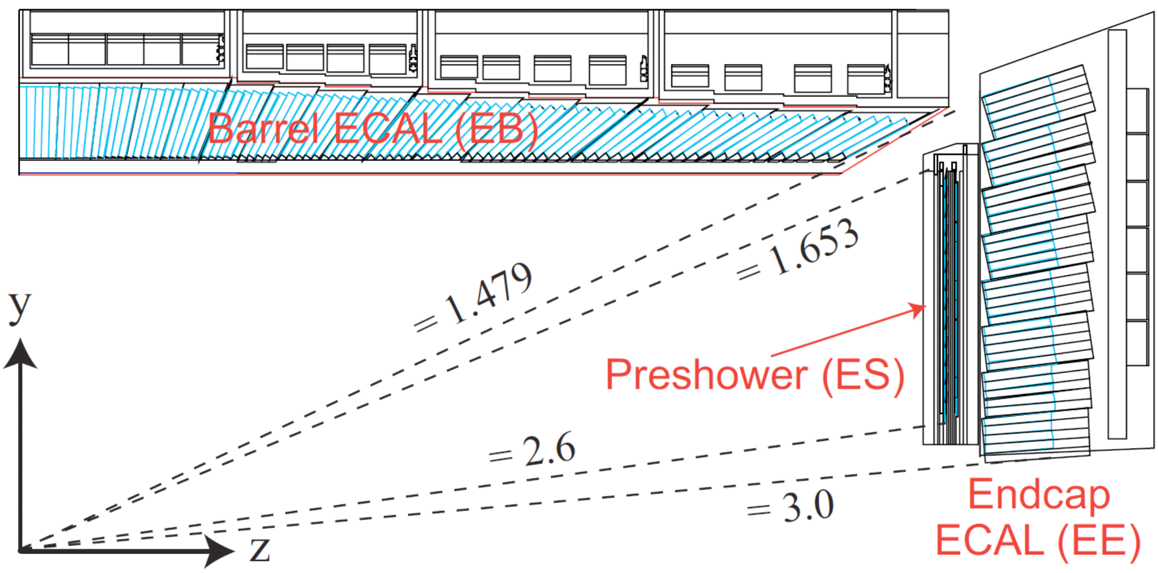

Figure 1.5: Geometric view of one quarter of the ECAL (top). Layout of the CMS electromagnetic calorimeter presenting the arrangement of crystal modules, supermodules, endcaps and the preshower in front (bottom) [1].

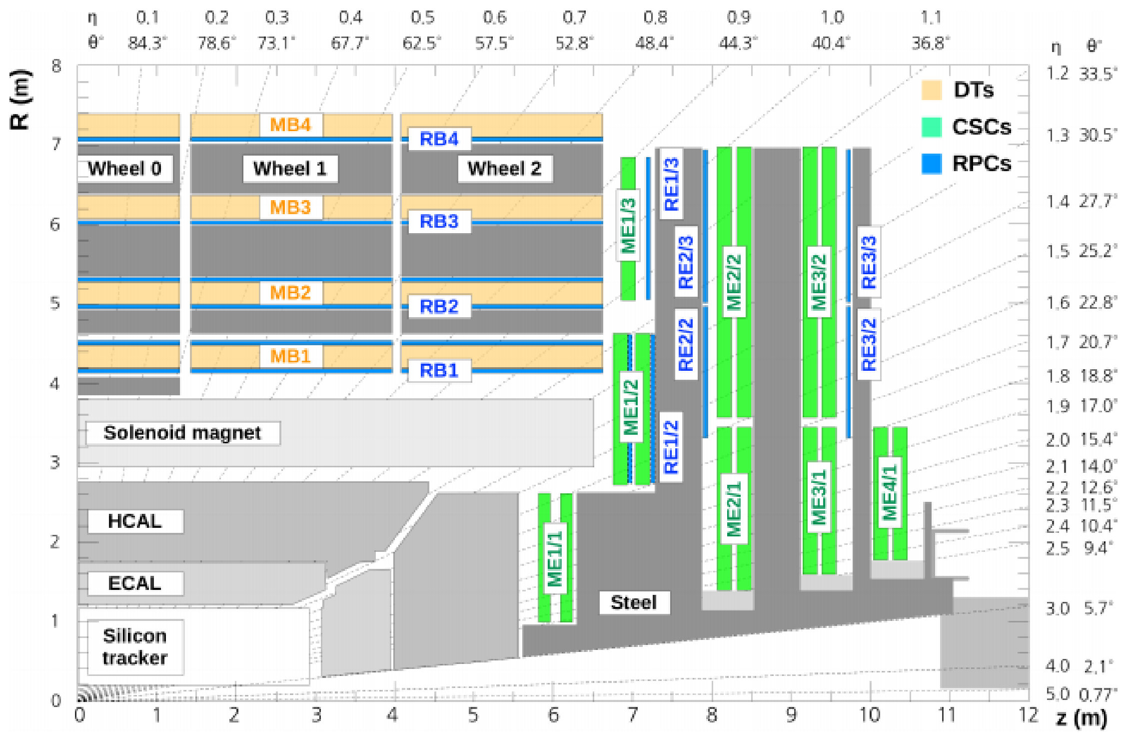

Figure 1.6: Layout of one quadrant of CMS. The figure shows the four DT stations in the barrel (MB1-MB4, yellow), the four CSC stations in the endcap (ME1-ME4, green), and the RPC stations (RB1-RB4 and RE1-RE3) [1].

1.4 Electromagnetic Calorimeter

1.5 Hadron Calorimeter

1.6 Superconducting Solenoid

1.7 Muon System

1.8 Trigger

1.9 Particle Reconstruction

1.9.1 Electron identification

1.9.2 Muon reconstruction

1.9.3 Jet reconstruction

Jet energy corrections

Particle flow jet identification

1.10 Computing

1.10.1 Event Data Model

1.10.2 Analysis Software

1.11 Monte Carlo Simulation

1.11.1 Monte Carlo event generators

	PU_RD1_START53_V7N-v1/AODSIM		
$t\bar{t}$(*Leptonic*)	/TTJets_FullLeptMGDecays_8TeV-madgraph/Summer12_DR53X-PU_S10_START53_V7A-v2/AODSIM	245.8	12119013
$t\bar{t}$(*Hadronic*)	/TTJets_HadronicMGDecays_8TeV-madgraph/Summer12_DR53X-PU_S10_START53_V7A_ext-v1/AODSIM	245.8	31223821
$t\bar{t}$(*Semileptonic*)	/TTJets_SemiLeptMGDecays_8TeV-madgraph/Summer12_DR53X-PU_S10_START53_V7A_ext-v1/AODSIM	245.8	25424818
$t\bar{t}$(*Inclusive*)	/TTJets_MassiveBinDECAY_TuneZ2star_8TeV-madgraph-tauola/Summer12_DR53X-PU_S10_START53_V7C-v1/AODSIM	245.8	6923652
Drell-Yann, $10 < m\_ll < 50$	/DYJetsToLL_M-10To50_TuneZ2Star_8TeV-madgraph/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	11050.0	37835275
Drell-Yann, $m\_ll > 50$	/DYJetsToLL_M-50_TuneZ2Star_8TeV-madgraph-tarball/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	3350.0	30459503
Single Top tW	/T_tW-channel-DR_TuneZ2star_8TeV-powheg-tauola/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	11.1	497658
Single TopBar tW $\bar{t}$	/Tbar_tW-channel-DR_TuneZ2star_8TeV-powheg-tauola/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	11.1	493460
Single Top t	/T_t-channel_TuneZ2star_8TeV-powheg-tauola/Summer12_DR53X-PU_S10_START53_V7A-v3/AODSIM	56.4	99876
Single TopBar t	/Tbar_t-channel_TuneZ2star_8TeV-powheg-tauola/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	30.7	1935072
Single Top s	/T_s-channel_TuneZ2star_8TeV-powheg-tauola/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	3.79	259961
Single TopBar s	/Tbar_s-channel_TuneZ2star_8TeV-powheg-tauola/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	1.76	139974
W+Jets	/WJetsToLNu_TuneZ2Star_8TeV-madgraph-tarball/Summer12_DR53X-PU_S10_START53_V7A-v2/AODSIM	36257.2	57709905
Diboson WW	/WW_TuneZ2star_8TeV_pythia6_tauola/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM	56.0	10000431

Chapter 2

Measurement of the inclusive $t\bar{t}+\gamma$ cross-section

2.1 Signal Definition and Background Processes

2.1.1 Signal definition

2.1.2 Background processes

2.2 $t\bar{t}+\gamma$ Signal Simulation

WHIZARD

then

MADGRAPH

Factorised matrix element

2.3 Phase Space Overlap Removal

2.4 Event Selection

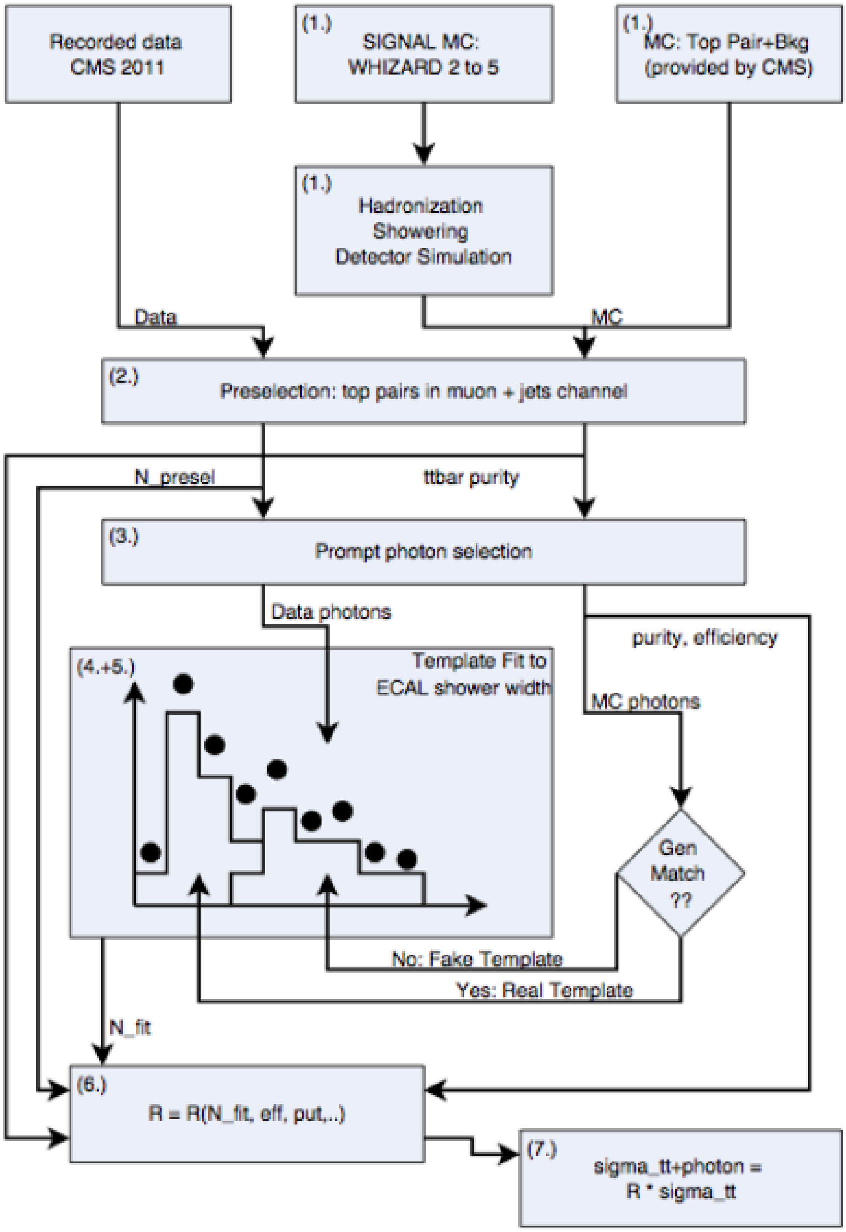

Figure 2.1: Flow chart showing each stage of the analysis. The box numbers represent the outlined analysis steps.

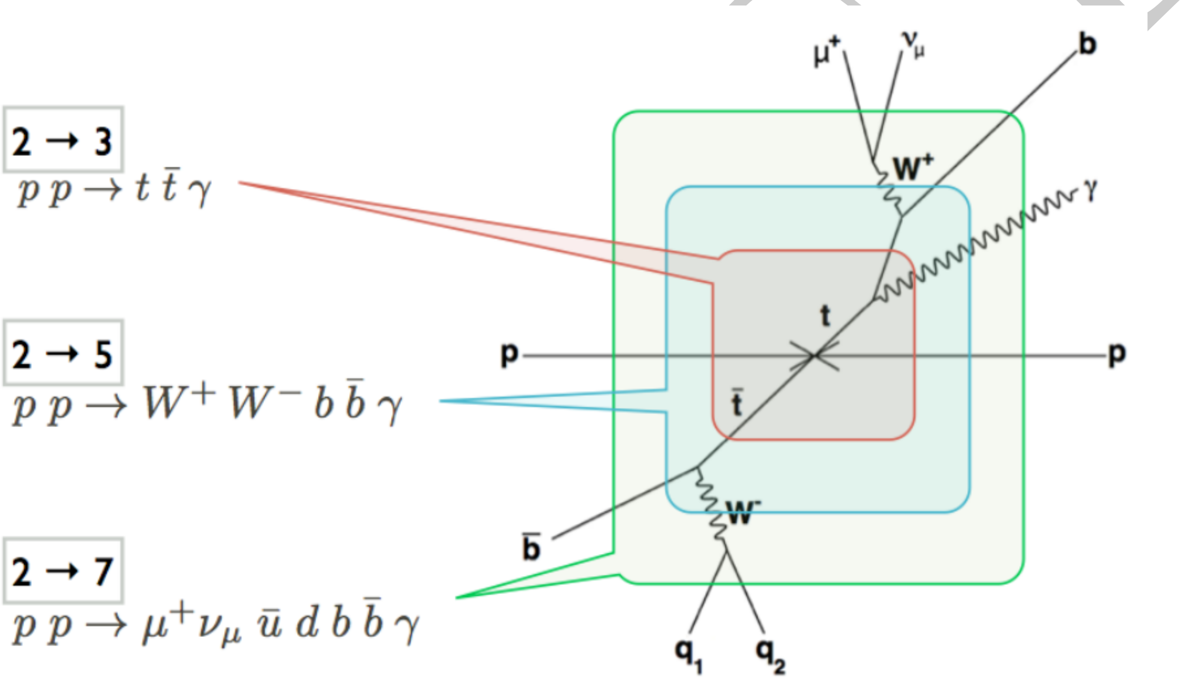

Figure 2.2: Three different methods to define the signal process [2].

Chapter 3

Measurement of the anomalous couplings of the photon to the top quark

Chapter 4

Electron Conversion Veto

Conclusions

Appendices

Bibliography

[1] CMS Collaboration. The cms experiment at the cern lhc. *JINST*, 3:S08004, 2008.

[2] H. J. A. Tholen and A. Stah. Study of the inclusive $t\bar{t} + \gamma$ cross-section with the cms experiment. *https://cds.cern.ch/record/1505276*, pages no. CERN–THESIS–2012–222, 2012.