Di-photon background studies for HH→ bbγγ analysis in CMS

Soumya Mukherjee

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About myself

I am a PhD student in **Tata Institute of Fundamental Research, Mumbai** from 2018
Working in CMS experiment with **Run-2 data**

Thesis topic:

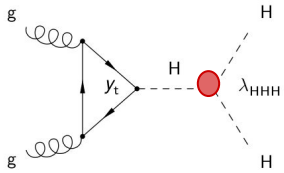
(i) Non resonant di-Higgs production in bbγγ final state. JHEP 03 (2021) 257
(ii) Measurement of Higgs coupling with b-quarks in Vector Boson Fusion production mode.
(iii)Missing transverse energy (MET) object reconstruction in CMS detector

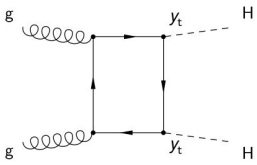
Currently I am in **University of Manchester** working with **Prof. Mike Seymour** for MCnet project

→ Study of diphoton production in LHC with Herwig

Introduction to non-resonant HH process

- Non-resonant HH process → able to directly probe **Higgs self coupling (λ_{HHH})** at the LHC
- $\lambda_{HHH} = \lambda$ is one of the most important characteristics of the Higgs boson, but yet to be measured
- Major production mode is : Gluon-gluon fusion
- Cross section is small due to the negative interference between the two diagrams





Gluon-Gluon Fusion (ggHH)
x-sec at N2LO QCD accuracy:
@ 13 TeV 31.05 +2.2% / -5.1% fb
@ 14 TeV 36.69 +2.1% / -4.9% fb

- Coupling parameters are measured in terms of coupling modifiers wrt SM in κ - framework

$$\kappa_t = \frac{y_t^{obs}}{y_t^{SM}} \qquad \boxed{\kappa_\lambda = \frac{\lambda^{obs}}{\lambda^{SM}}}$$

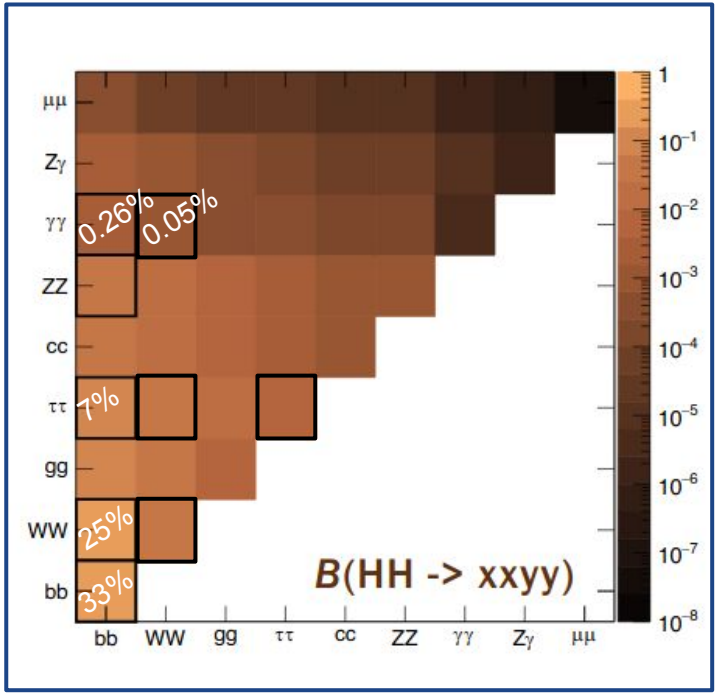
HH search in LHC

- HH decay modes being explored using **full Run2 (137 fb^{-1})** data both by CMS & ATLAS:
- Modes with large branching ratios (BR) utilized for atleast one of the H decays :

  → bb (58%) and WW*(21%)

- HH→ 4b , bb$\tau\tau$, **bb$\gamma\gamma$**, bbWW, bbZZ, 4W, WW$\tau\tau$, 4τ, WW$\gamma\gamma$

- Despite of small branching ratio of H→$\gamma\gamma$, due to good ecal resolution and comparatively less background, HH → **bb$\gamma\gamma$ is the on of the best sensitive channel.**



Important features

Event selections Data and MC photons, b -jet selection	Signal Vs Background separation	Construction of analysis categories based on purity	Fitting the signal and background $m_{\gamma\gamma}$ and m_{bb}	Extraction of results

- **Why MC is important in this analysis**
  Although the final results derived by the direct **fitting of data** assuming the **full background**
  But for the training and validation of any multivariate training (BDT or DNN), we have to rely on MC background instead of data to get rid of the any kind of bias.

- **Current scenario**
  The major background in this analysis is $\gamma\gamma/\gamma$ + jets.
  The current available MC samples for $\gamma\gamma/\gamma$ + jets are not enough to follow the data, we have large deficiency of MC simulate events comparing to Data (factor 2.4).

- The same approach is being applicable for all $H\rightarrow\gamma\gamma$, although in single $H\rightarrow\gamma\gamma$ phase space the MC has better agreement with data

MC description of currently used γγ samples

→ Prompt di-photon production along with some jets (upto 3 jets)
Generator : Sherpa
Additional : Invariant mass of two photons $m_{\gamma\gamma} >$ 80 GeV

→ Fake - prompt production
Generator : Pythia
Additional : EM-Enriched filter applied to enhance the fake photon contribution
Invariant mass of two photons $m_{\gamma\gamma} >$ 80 GeV

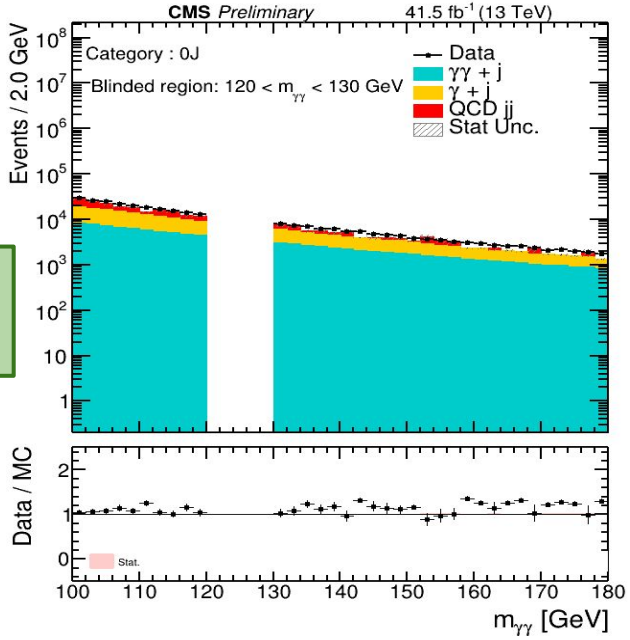
→ QCD fake - fake production
Generator : Pythia
Additional : Double EM Enriched filter applied to have two isolated photons
Invariant mass of two photons $m_{\gamma\gamma} >$ 80 GeV
Problem: Very low filter efficiency , high weights due to large cross section , small number of events selected
Current solutions: Data-Driven method from a control region orthogonal to signal or (analysis region)

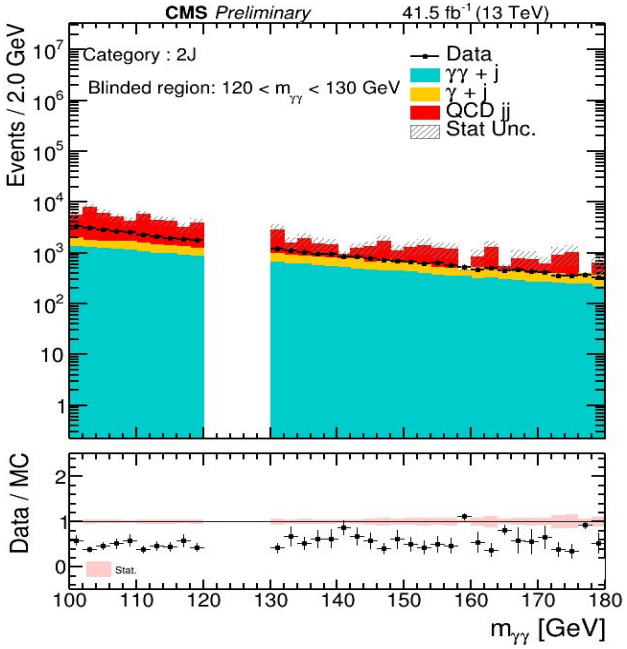
→ Prompt di-photon production along with 1/2 b-jets (upto total 3 jets)
Generator : Sherpa
Additional : Invariant mass of two photons $m_{\gamma\gamma} >$ 80 GeV

Important for HH→bbγγ

Diphoton variable modelling in Single - H → γγ analysis

GGH → γγ Phase space



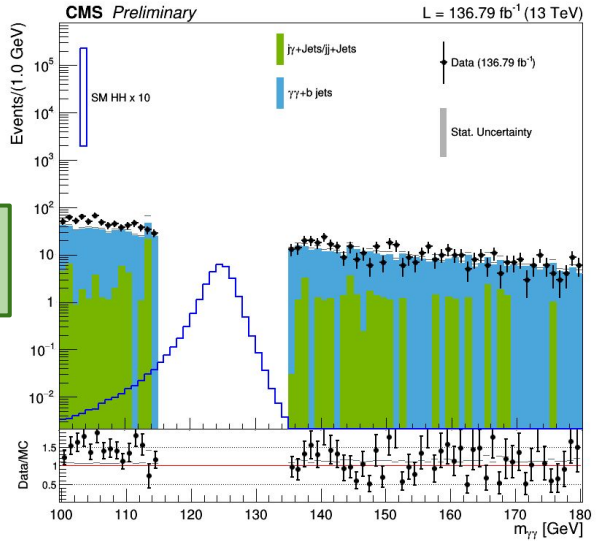


VBFH → γγ Phase space

→ For the GGH → γγ process where no requirements on jets , MC prediction agrees with data well
→ Problem arises when there is some jet requirements, overestimation of fake - photon contributions

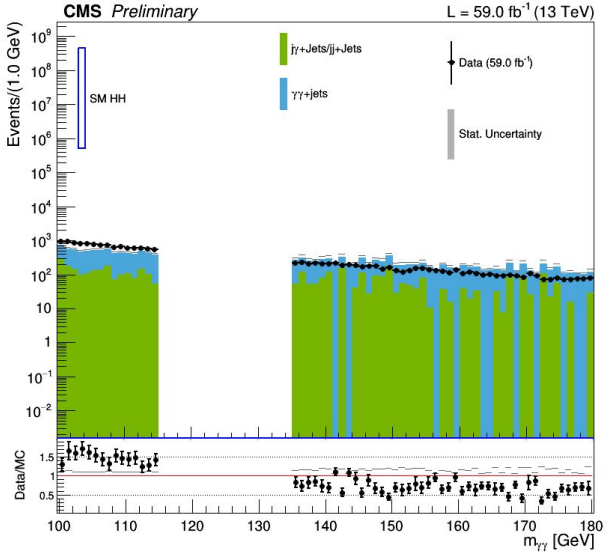
Diphoton variable modelling in HH → bbγγ analysis

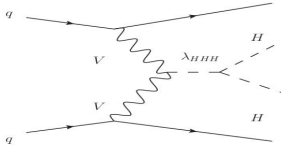
HH → bbγγ phase space



GGHH → bbγγ Phase space

VBF HH → bbγγ phase space





VBF HH → bbγγ Phase space

→ Overall normalization factors has been applied to the **γγ** + jets contributions for **HH→ bbγγ is 2.4** and for **VBFHH → bbγγ is 4.4**

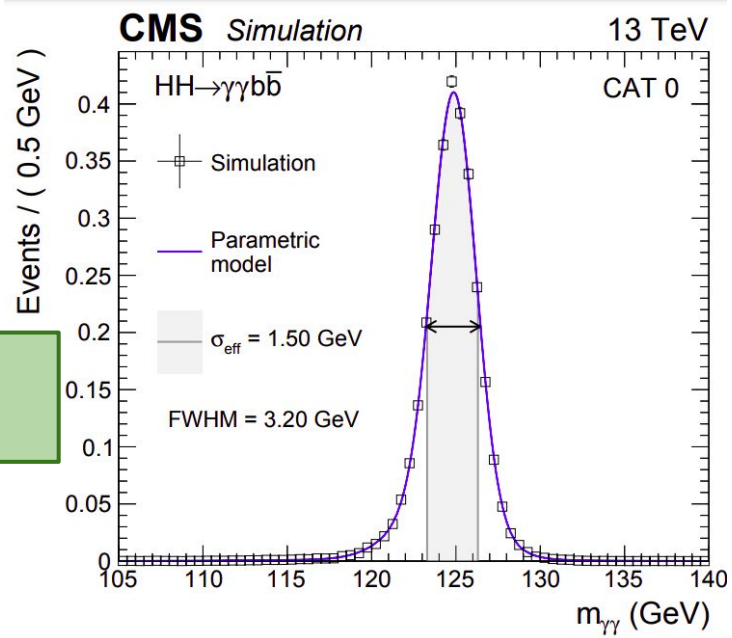
→ The normalization factors are basically high compared to the usual **k-factors** for different processes.

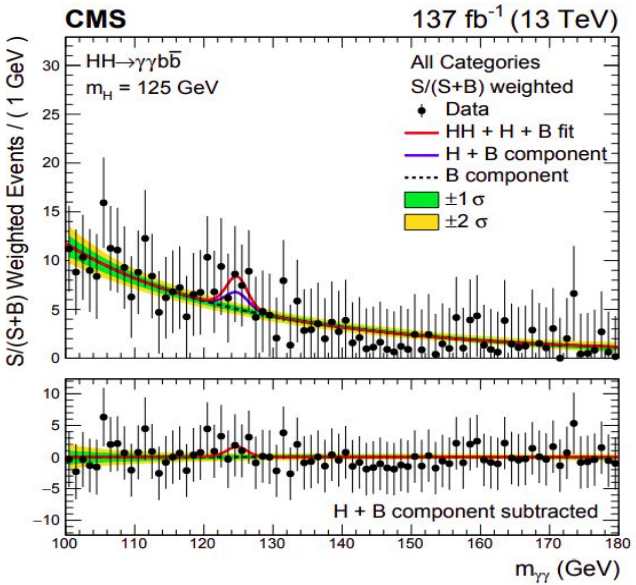
→ The main reason for this is mis-modelling of **γγ** + jets monte carlo which can't follow the data

Signal and background spectrum fitting

JHEP 03 (2021) 257

Signal modelling





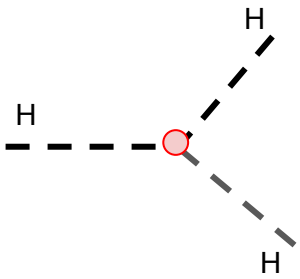
Background Fitting

→ The signal has been modelled from MC simulation using multi gaussian fits
→ The background contributions has been estimated directly from data using exponential function.

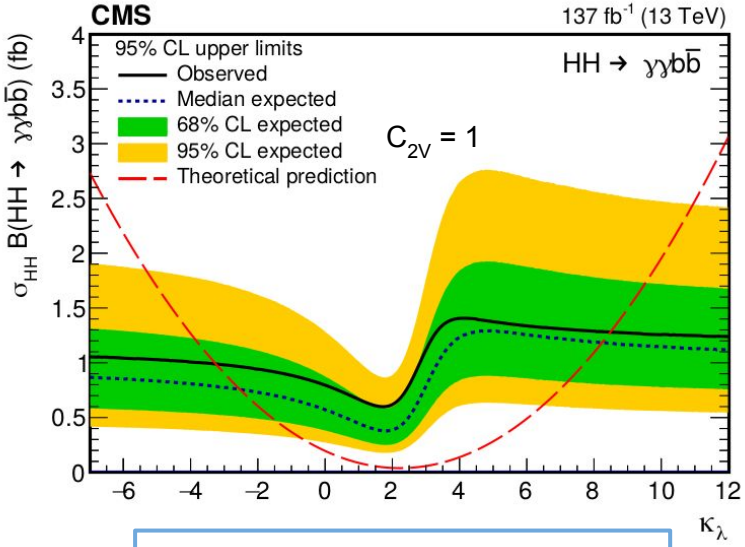
Results from Run-2 data from LHC (CMS only)

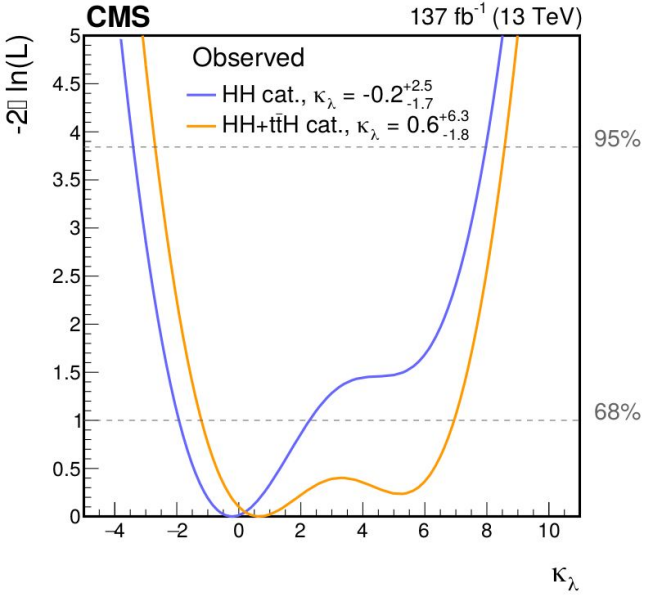
JHEP 03 (2021) 257

Allowed range @ 95% CL



$$\kappa_\lambda = \frac{\lambda_{\mathrm{HHH}}}{\lambda_{\mathrm{HHH}}^{\mathrm{SM}}}$$





Observed: $-3.3 < \kappa_\lambda < 8.5$

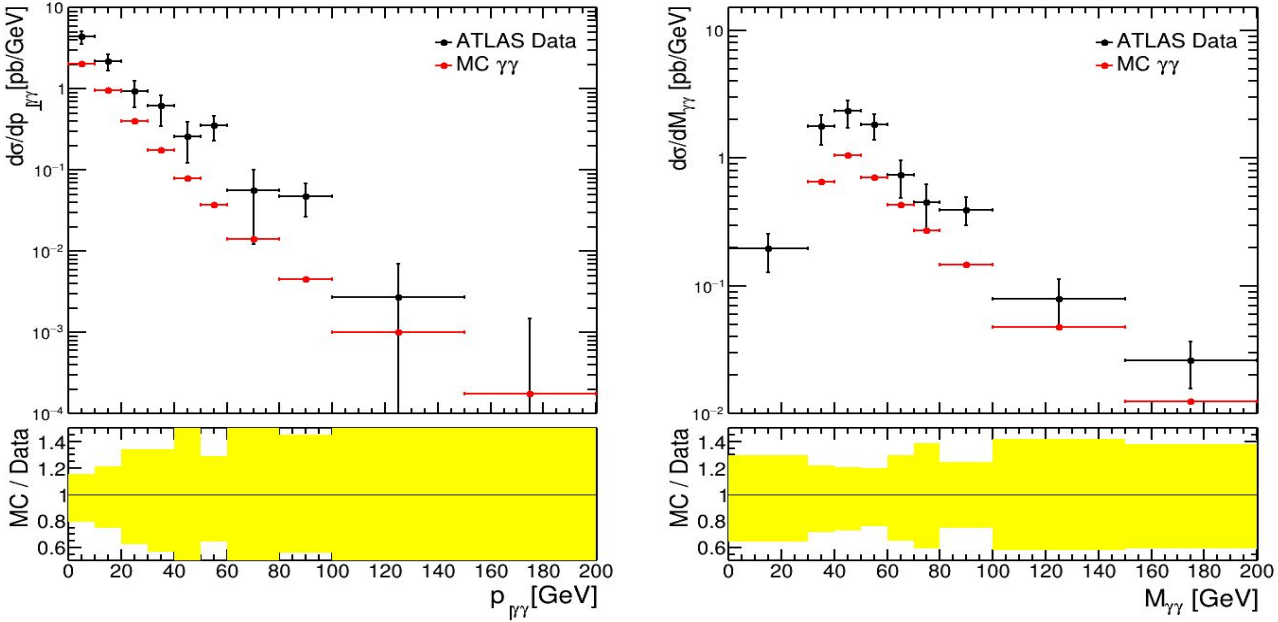
Expected: $-2.5 < \kappa_\lambda < 8.2$

95% CL Upper Limit on (inclusive cross section*BR)

Inclusive HH (* SM)	
Observed	7.7
Expected	5.2

Current studies with Herwig interface

→ I have started with in-build γγ production module : MEGammaGamma



→ **ATLAS 2011_S9120807 @CoM 7 TeV used as reference**

Plan

- We have seen to analyse **Run-2** data for **HH→ bbγγ** that the available set of MC samples are not sufficient.
- In CMS currently no **Herwig diphoton background sample** is available so far.
- I have currently started diphoton production in LHC through standalone **Herwig7** (not included in CMS environment) , **ATLAS 7 TeV** data used as reference
- Shape of MC distributions follows data but disagreement founds in event yields, currently working on it.
- Once diphoton background production will be done with good agreement with data-mc , I will go specifically for the production of **γγ** along with 2 -bjets in Herwig
- Final target is to include the model in **Run-3 CMS** analysis.