Upgrade VBF $\mathrm{H} \to \gamma\gamma$ analysis

IHEP

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Physics background

Upgrade LHC at $\sqrt{s} = 14TeV$ has different cross section and performance compared with 13TeV

Do some MC simulation in VBF $H \rightarrow \gamma\gamma$ events to analysis the influences of these differences

MC sample

- **Row Monte Carlo sample:**

  Signal: VBF

  mc15_14TeV.160024.PowhegPythia8_AU2CT10_VBFH125_gamgam.merge.DAOD_TRUTH3.e1337_p2768

  Background:

  ggH event:

  mc15_14TeV.341000.PowhegPythia8EvtGen_CT10_AZNLOCTEQ6L1_ggH125_gamgam.merge.DAOD_TRUTH3.e5529_p2768

  QCD

  process:mc15_14TeV:mc15_14TeV.181782.MadGraphPythia8_AU2CTEQ6L1_GammaGammaJetJet.merge.DAOD_TRUTH3.e2473_p2768

Event reconstruction and selection

➢Smearing function

Use Upgrade Performance Function

Detector layouts: reference scenario with LoI strips, LoI-VF pixels to η=4.0, sFCal, new BI RPC and sMDT

Average pileup values: $\langle\mu\rangle = \frac{\mathcal{L}\times\sigma_{inel}}{n_b \times f_r} \sim \mathcal{L} = 200$

Electron performance:

- Working point: looseElectron
- Requiring pT>10 GeV, |eta|<2.47, and remove eta crack region [1.37, 1.52]
- including fake electron from HS jet

Photon performance:

- Working point: tightPhoton
- Requiring pT>25 GeV, |eta|<2.37, remove eta crack region [1.37, 1.52]
- Including fake photon from electron, HS jet, PU jet

Event reconstruction and selection

➢Smearing function

Muon performance

- tight muon
- Requiring pT>10GeV, |eta|<2.7

Jet performance

- Hard scattering jets and pile up jets all require pT>25GeV, |eta|<4.5, track confirmation

Event reconstruction and selection

➢Overlap removal

Remove objects in close region to prevent potential double-counting of objects in the detector

Order:

1. Remove electrons within $\Delta R = 0.4$ of any photon
2. Remove muons within $\Delta R = 0.4$ of any photon
3. Remove jets within $\Delta R = 0.4$ of any photon
4. Remove jets within $\Delta R = 0.2$ of any electron
5. Remove electrons within $\Delta R = 0.4$ of any jet
6. Remove muons within $\Delta R = 0.4$ of any jet

Event reconstruction and selection

➢ $H \rightarrow \gamma\gamma + jj$ event selection

Cut-based selection for $\gamma\gamma + jj$ event

- Number of jets ≥ 2
- Number of photon ≥ 2
- $\frac{pT_{leading\ photon}}{m_{\gamma\gamma}} > 0.35$
- $\frac{pT_{sub-leading\ photon}}{m_{\gamma\gamma}} > 0.25$
- $105\ GeV < m_{\gamma\gamma} < 160\ GeV$

MVA VBF category

➢Preselection:

$\Delta\eta_{jj} > 2, |\eta_{\gamma\gamma}^{Zepp}| < 5$ to help BDT focus on VBF event phase-space

➢BDT training

VBF vs Madgraph background training

type	Sample	Number of events
Signal	VBF	28721
Background	MC Madgraph QCD	9063
we abandoned ggH background in training because of its low cross section*branching ratio The samples are separated into 2 trees apart for training(70%) and testing(30%)		

MVA VBF category

➢Selection efficiency

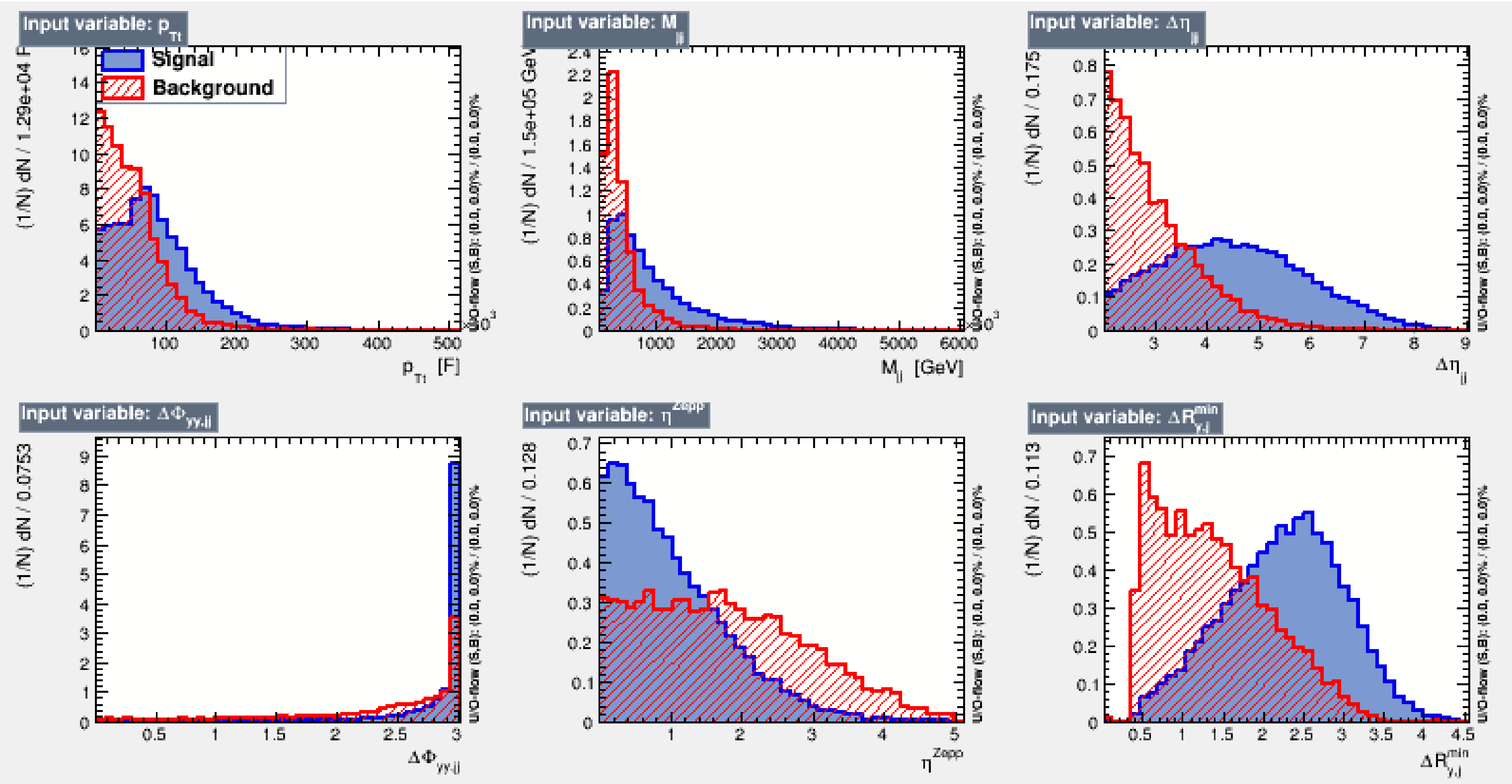
	VBF	ggH	QCD background
$N_{\gamma} \geq 2$	0. 273	0. 235	0. 215
$\frac{pT}{m_{\gamma\gamma}} \geq 0.35(0.25)$	0. 891	0. 931	0. 795
$105 < m_{\gamma\gamma} < 160$	0. 954	0. 974	0. 262
$N_{jet} \geq 2$	0. 423	0. 091	0. 583
$\Delta\eta_{jj} > 2$	0. 836	0. 414	0. 281
$\left\|\eta_{\gamma\gamma}^{Zepp}\right\| < 5$	0. 999	0. 996	0. 992
Total	0. 082	0. 008	0. 007

MVA VBF category

6 BDT training variables

Variable	Description
m_{jj}	Invariant mass of leading 2 jets
$\Delta\eta_{jj}$	Pseudorapidity separation between the leading 2 jets
p_{Tt}	Diphoton pT projected perpendicular to the diphoton thrust axis
$\Delta\phi_{\gamma\gamma,jj}$	Azimuthal angle between the diphoton and dijet systems
$\Delta R_{\gamma,j}^{min}$	Minimum ΔR between leading/subleading photon and the leading/subleading jet
$\eta_{\gamma\gamma}^{Zepp}$	Zeppenfeld variable $\eta_{\gamma\gamma} - (\eta_{j1} + \eta_{j2})/2$

MVA VBF category



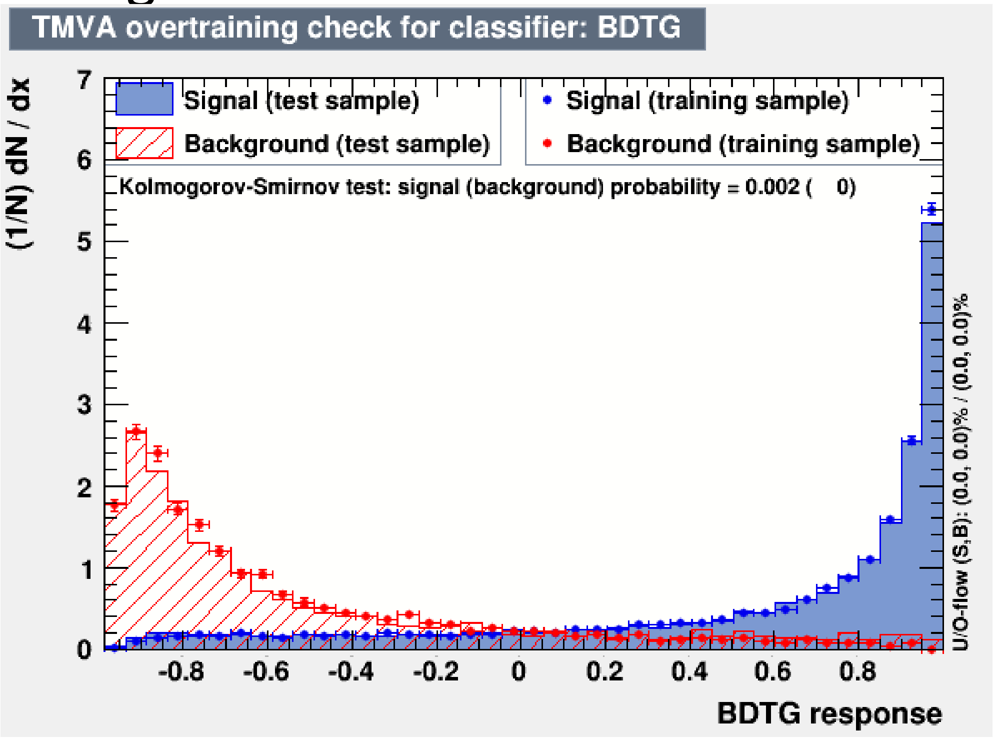
Distribution of input variables

MVA VBF category

BDT training options:

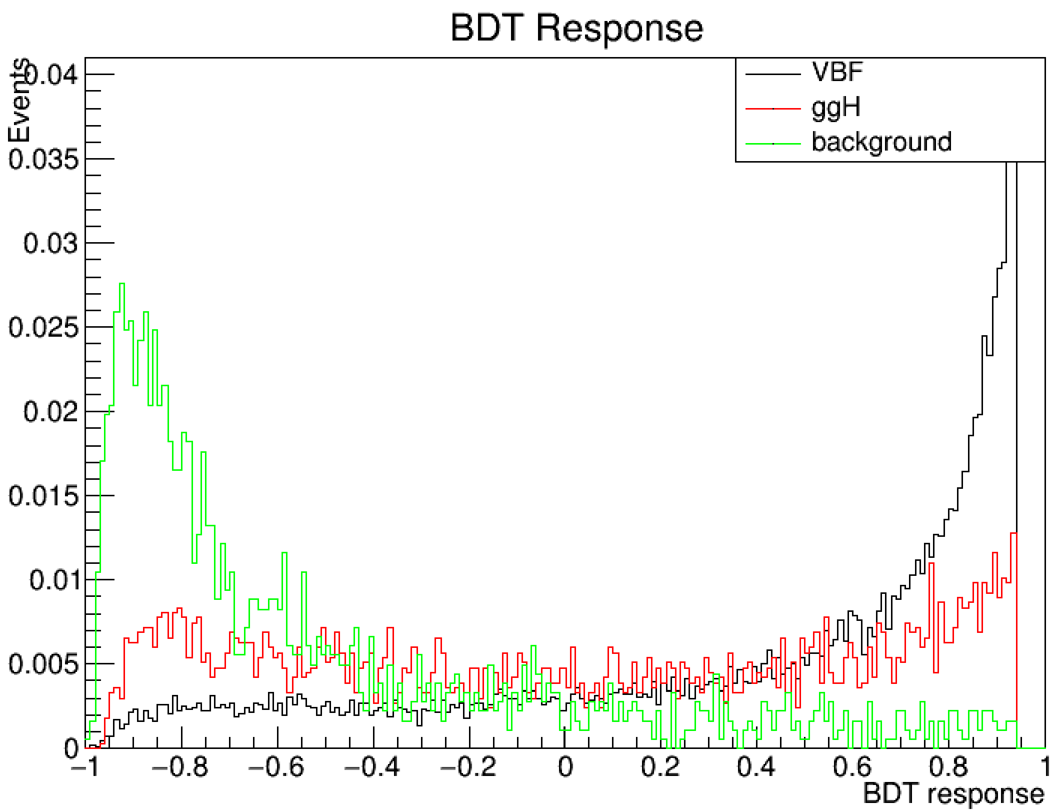
NTrees=900: nEventsMin=50: BoostType=Grad: Shrinkage=0.06: UseBaggedGrad: GradBaggingFraction=0.6: nCuts=20: MaxDepth=4

Output of training



MVA VBF category

- BDT out of three samples



MVA VBF category

➢Choice of optimal BDTG event categorization

Scan Kcut on BDTG response to maximize VBF significance

$$\sigma_{VBF} = \sqrt{2 \times ((N_{VBF} + N_{ggH} + N_{bkg}) \times \ln\left(1 + \frac{N_{VBF}}{N_{ggH} + N_{bkg}}\right) - N_{VBF})}$$

N_{VBF}:VBF event number satisfying BDTG>Kcut in $m_{\gamma\gamma}$ window [120,130]GeV

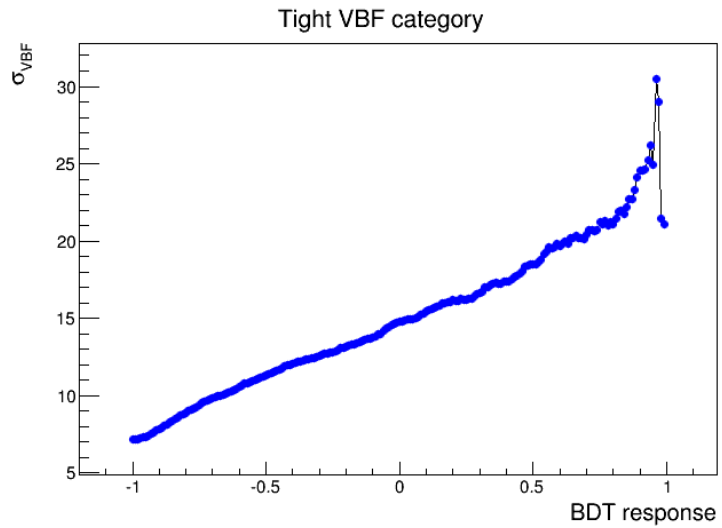
N_{ggH}:ggH event number satisfying BDTG>Kcut in $m_{\gamma\gamma}$ window [120.130]GeV

N_{bkg}:Madgraph QCD background event number satisfying BDTG>Kcut in $m_{\gamma\gamma}$ window [120,130] GeV

MVA VBF category

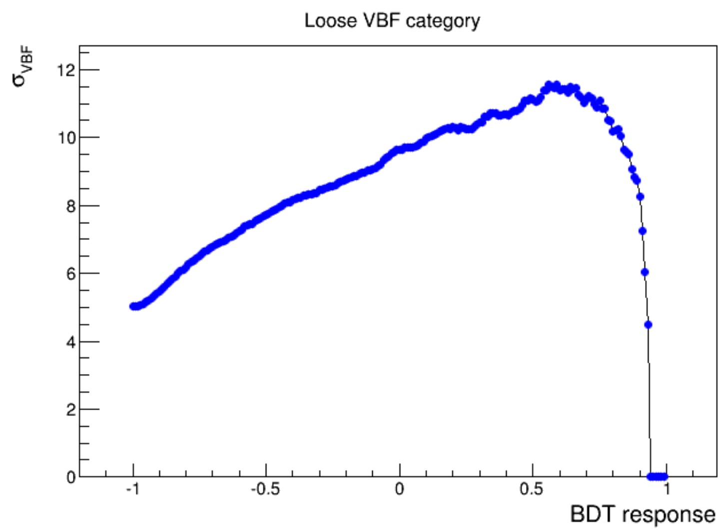
Tight VBF category: determine $kCut_{tight}$ with maximum σ_{VBF} using all events(abandon oscillation nearby 1)

0.94



Loose VBF category: determine kCut in the same way using events with BDTG<$kCut_{tight}$

0.56



MVA VBF category

➢Results

	Loose(0.56<BDTG<0.94)	**Tight(BDTG>0.94)**
VBF signal	10124.2	8049.89
ggH	84575.9	25382.1
background	679113	66435
VBF purity	10.690	24.080
VBF significance	11.56	26.19
combined significance	28.63	

The event number are calculated in mass window [120,130]GeV, weighted to $\int L = 3000\ fb^{-1}$ luminosity. Combined significance is the quadratic sum of significance in loose and tight VBF categories

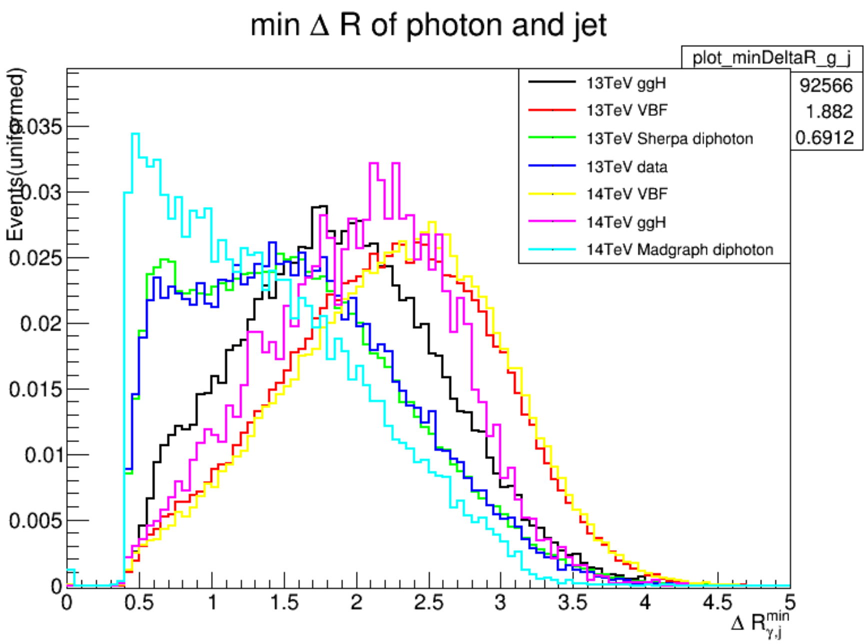
Further work

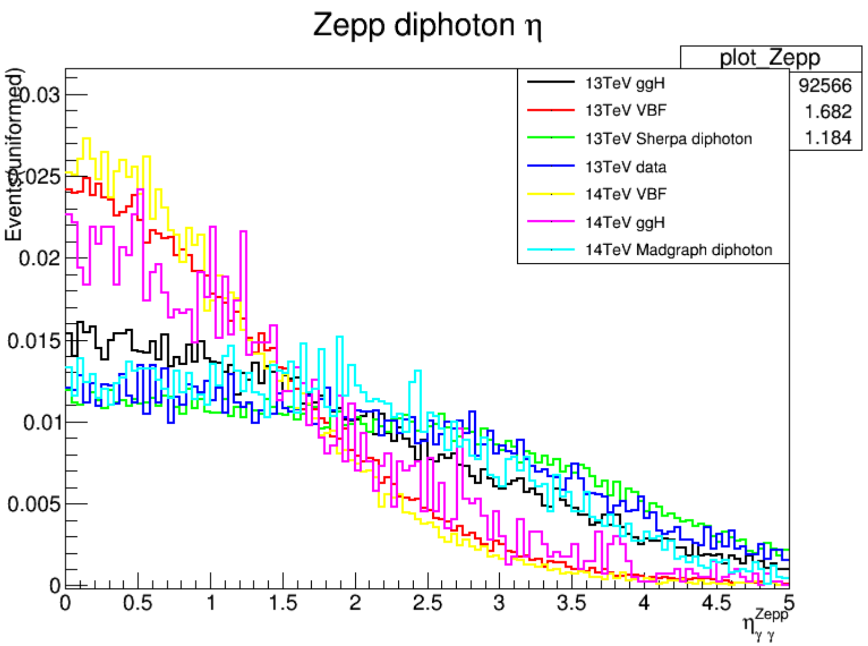
- Tuning BDT to seek better performance
  - 2-D BDT to enhance VBF purity

- Fit diphoton mass distribution and do other measurements

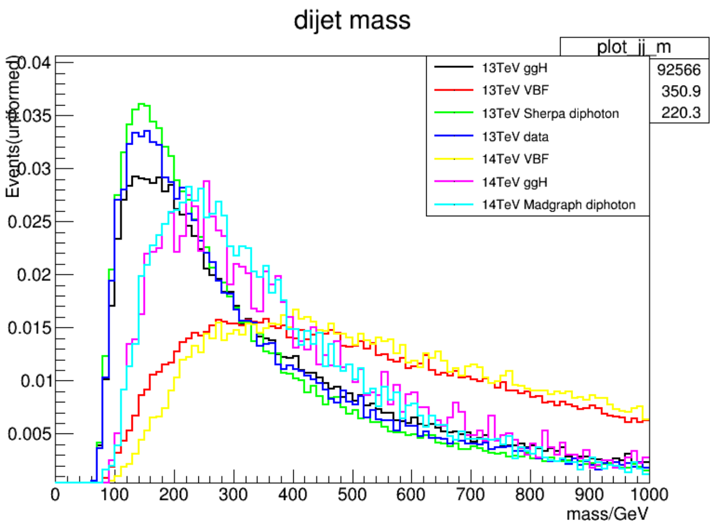
Back up

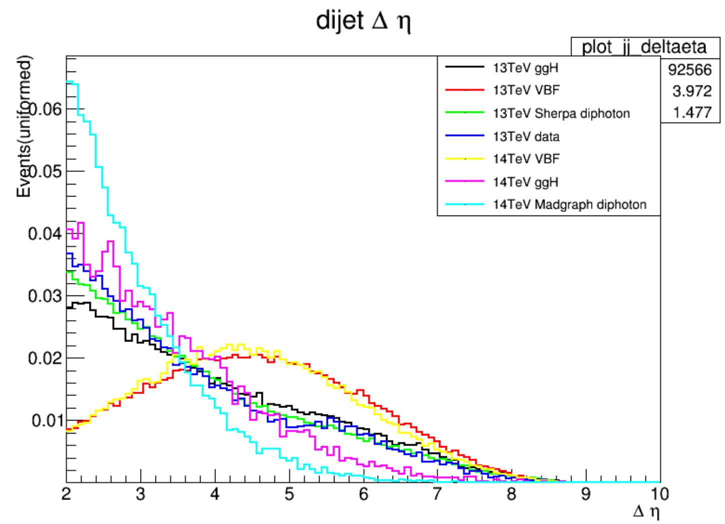
➢ Variable distribution(including 13TeV)

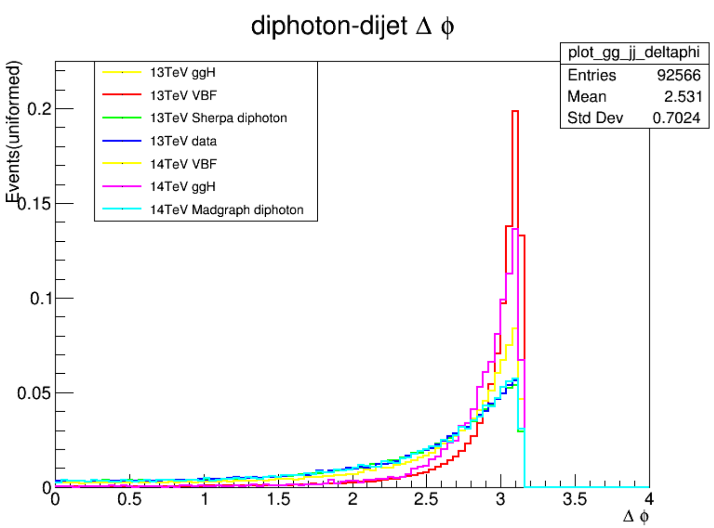


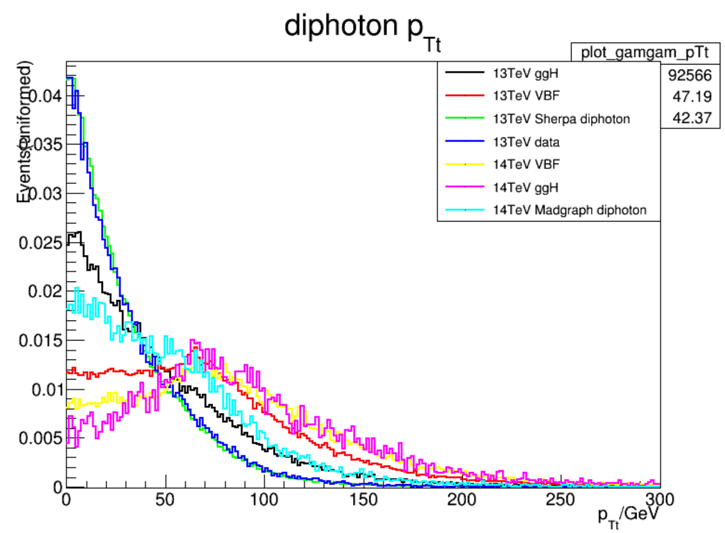


Back up

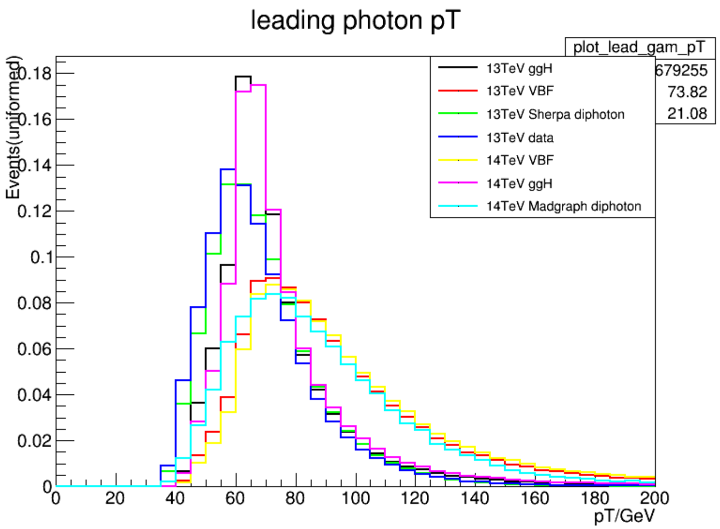

dijet mass
plot_jj_m
92566
350.9
220.3
13TeV ggH
13TeV VBF
13TeV Sherpa diphoton
13TeV data
14TeV VBF
14TeV ggH
14TeV Madgraph diphoton
Events(uniformed)
mass/GeV


dijet Δ η
plot_jj_deltaeta
92566
3.972
1.477
13TeV ggH
13TeV VBF
13TeV Sherpa diphoton
13TeV data
14TeV VBF
14TeV ggH
14TeV Madgraph diphoton
Events(uniformed)
Δ η

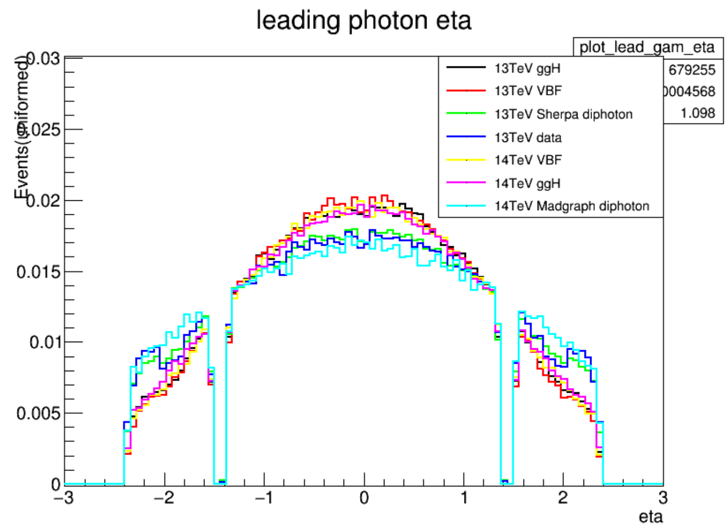

diphoton-dijet Δ ϕ
plot_gg_jj_deltaphi
Entries 92566
Mean 2.531
Std Dev 0.7024
13TeV ggH
13TeV VBF
13TeV Sherpa diphoton
13TeV data
14TeV VBF
14TeV ggH
14TeV Madgraph diphoton
Events(uniformed)
Δ ϕ


diphoton p_Tt
plot_gamgam_pTt
92566
47.19
42.37
13TeV ggH
13TeV VBF
13TeV Sherpa diphoton
13TeV data
14TeV VBF
14TeV ggH
14TeV Madgraph diphoton
Events(uniformed)
p_Tt/GeV

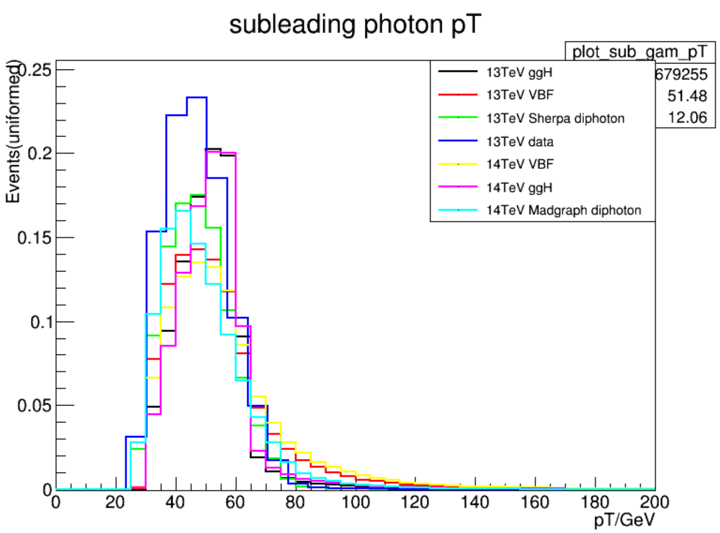
Back up



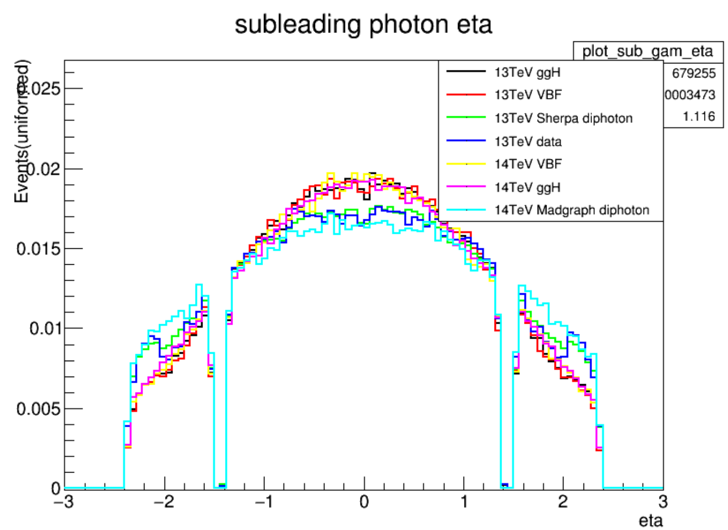
leading photon pT
plot_lead_gam_pT
679255
73.82
21.08
13TeV ggH
13TeV VBF
13TeV Sherpa diphoton
13TeV data
14TeV VBF
14TeV ggH
14TeV Madgraph diphoton
Events(uniformed)
pT/GeV



leading photon eta
plot_lead_gam_eta
679255
0004568
1.098
13TeV ggH
13TeV VBF
13TeV Sherpa diphoton
13TeV data
14TeV VBF
14TeV ggH
14TeV Madgraph diphoton
Events(uniformed)
eta

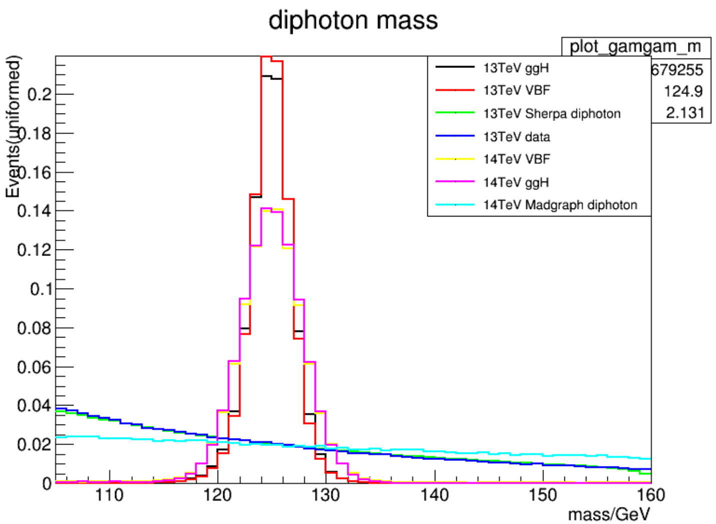


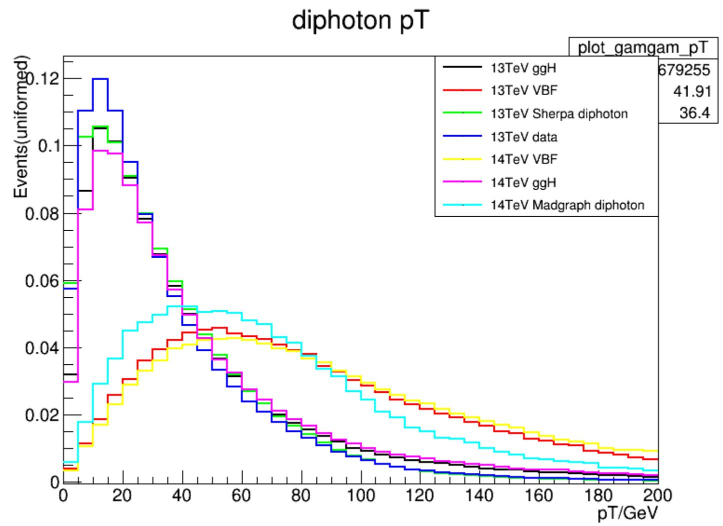
subleading photon pT
plot_sub_gam_pT
679255
51.48
12.06
13TeV ggH
13TeV VBF
13TeV Sherpa diphoton
13TeV data
14TeV VBF
14TeV ggH
14TeV Madgraph diphoton
Events(uniformed)
pT/GeV

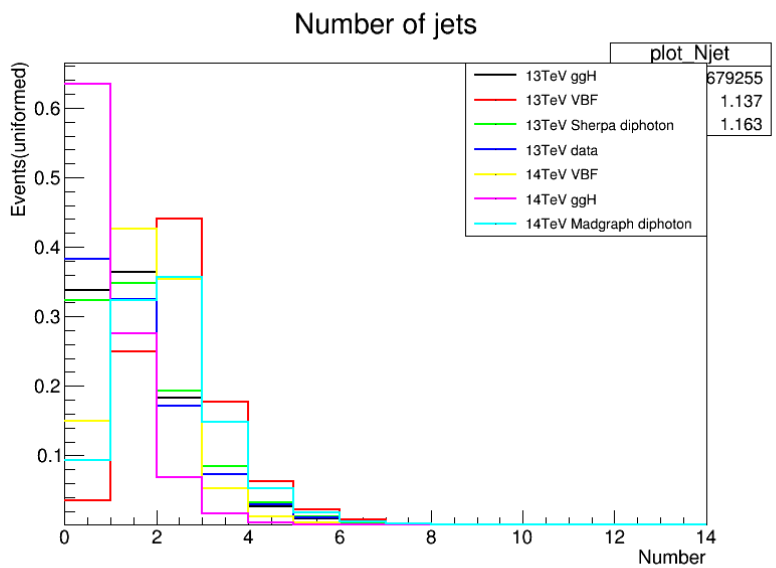


subleading photon eta
plot_sub_gam_eta
679255
0003473
1.116
13TeV ggH
13TeV VBF
13TeV Sherpa diphoton
13TeV data
14TeV VBF
14TeV ggH
14TeV Madgraph diphoton
Events(uniformed)
eta

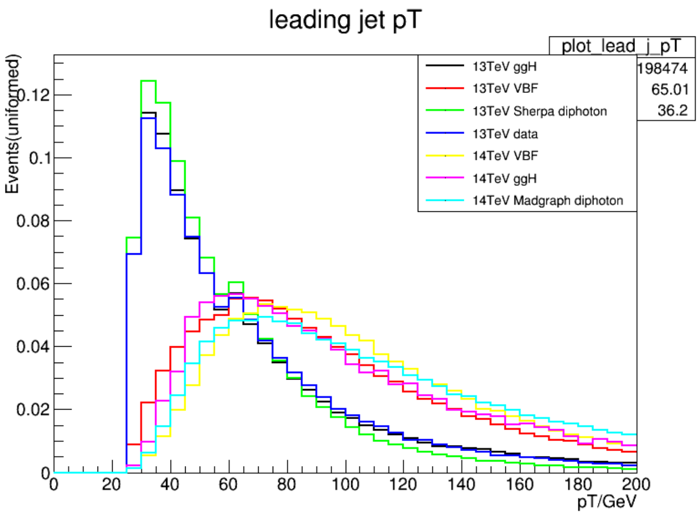
Back up

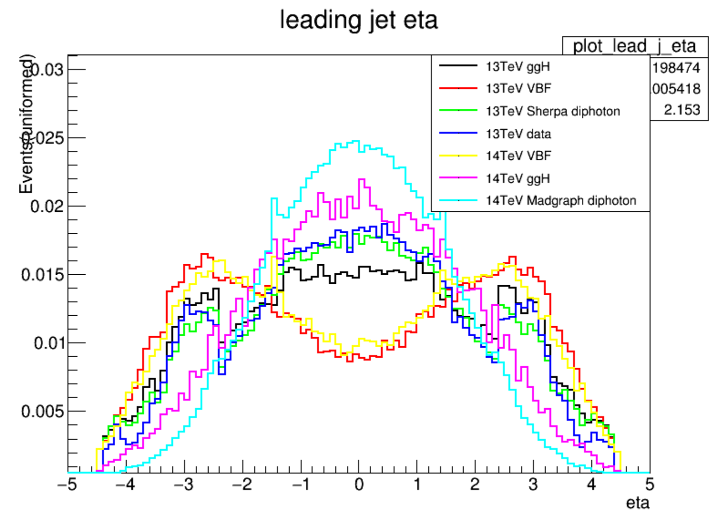

diphoton mass
plot_gamgam_m
679255
124.9
2.131
13TeV ggH
13TeV VBF
13TeV Sherpa diphoton
13TeV data
14TeV VBF
14TeV ggH
14TeV Madgraph diphoton
Events(uniformed)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
110
120
130
140
150
160
mass/GeV

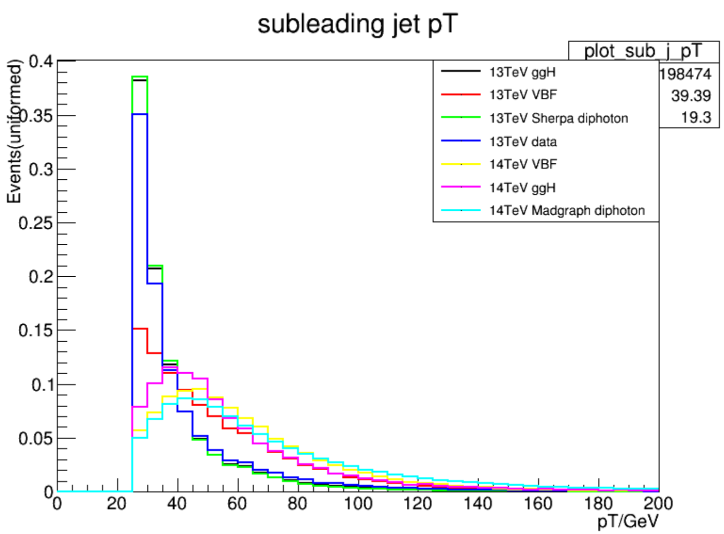

diphoton pT
plot_gamgam_pT
679255
41.91
36.4
13TeV ggH
13TeV VBF
13TeV Sherpa diphoton
13TeV data
14TeV VBF
14TeV ggH
14TeV Madgraph diphoton
Events(uniformed)
0
0.02
0.04
0.06
0.08
0.1
0.12
0
20
40
60
80
100
120
140
160
180
200
pT/GeV

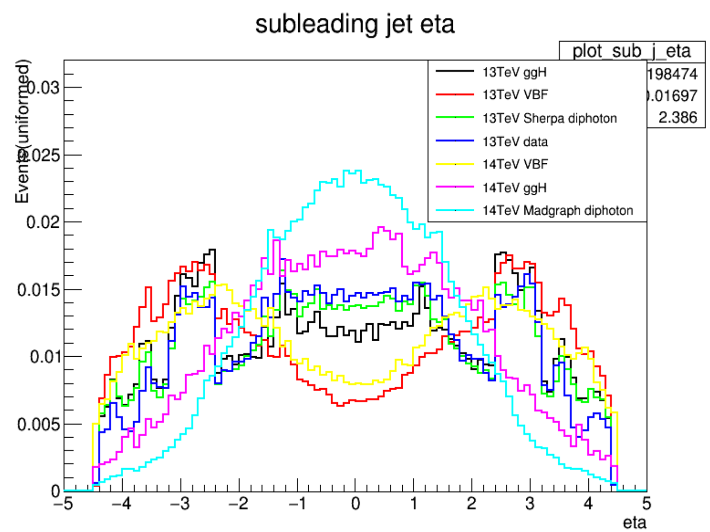

Number of jets
plot_Njet
679255
1.137
1.163
13TeV ggH
13TeV VBF
13TeV Sherpa diphoton
13TeV data
14TeV VBF
14TeV ggH
14TeV Madgraph diphoton
Events(uniformed)
0.1
0.2
0.3
0.4
0.5
0.6
0
2
4
6
8
10
12
14
Number

Back up


leading jet pT
plot_lead_j_pT
198474
65.01
36.2
13TeV ggH
13TeV VBF
13TeV Sherpa diphoton
13TeV data
14TeV VBF
14TeV ggH
14TeV Madgraph diphoton
Events(uniformed)
pT/GeV


leading jet eta
plot_lead_j_eta
198474
005418
2.153
13TeV ggH
13TeV VBF
13TeV Sherpa diphoton
13TeV data
14TeV VBF
14TeV ggH
14TeV Madgraph diphoton
Events(uniformed)
eta


subleading jet pT
plot_sub_j_pT
198474
39.39
19.3
13TeV ggH
13TeV VBF
13TeV Sherpa diphoton
13TeV data
14TeV VBF
14TeV ggH
14TeV Madgraph diphoton
Events(uniformed)
pT/GeV


subleading jet eta
plot_sub_j_eta
198474
.01697
2.386
13TeV ggH
13TeV VBF
13TeV Sherpa diphoton
13TeV data
14TeV VBF
14TeV ggH
14TeV Madgraph diphoton
Events(uniformed)
eta

Back up

➢BDT variable correlation matrix