APS DIVISION OF PARTICLES & FIELDS

DPF 2017

MEETING OF THE AMERICAN PHYSICAL SOCIETY DIVISION OF PARTICLES AND FIELDS

Search for SM Higgs Boson in the $H \rightarrow \tau^-\tau^+ \rightarrow \mu^-\mu^+\bar{\nu}_\mu\nu_\mu\nu_\tau\bar{\nu}_\tau$ decay mode with the CMS experiment at 13TeV

Vallary Bhopatkar
Florida Institute of Technology

On behalf of CMS Collaboration

July 31, 2017

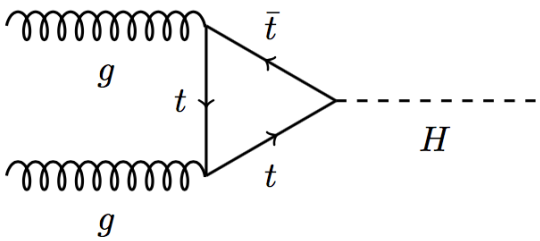
Outline

SM $\boldsymbol{H \rightarrow \tau\tau \rightarrow \mu\mu}$ analysis results using full 2016 dataset with $\sqrt{s}$ = 13TeV

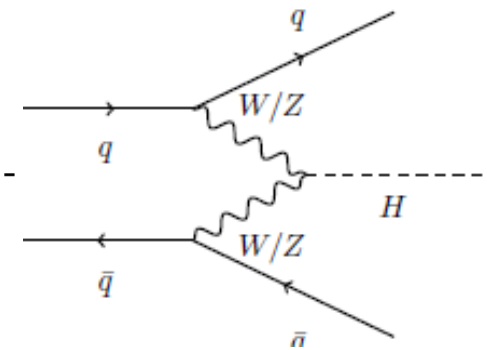
- SM Higgs: Overview
- Run II Analysis in $\boldsymbol{H \rightarrow \tau\tau \rightarrow \mu\mu}$ channel
  - Event selections
  - Event categorization
  - Multivariate analysis for background suppression
- Summary

Higgs!!
Production and decays at LHC

Higgs Production Modes

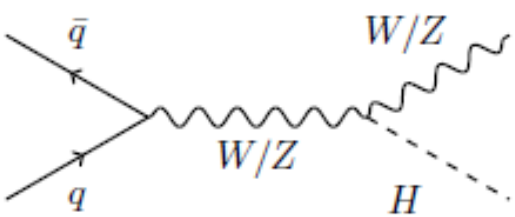


Gluon-Gluon Fusion
(GGF, ggH)

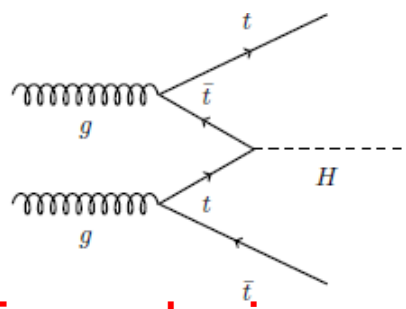


Vector Boson Fusion
(VBF, qqH)

Production in association with

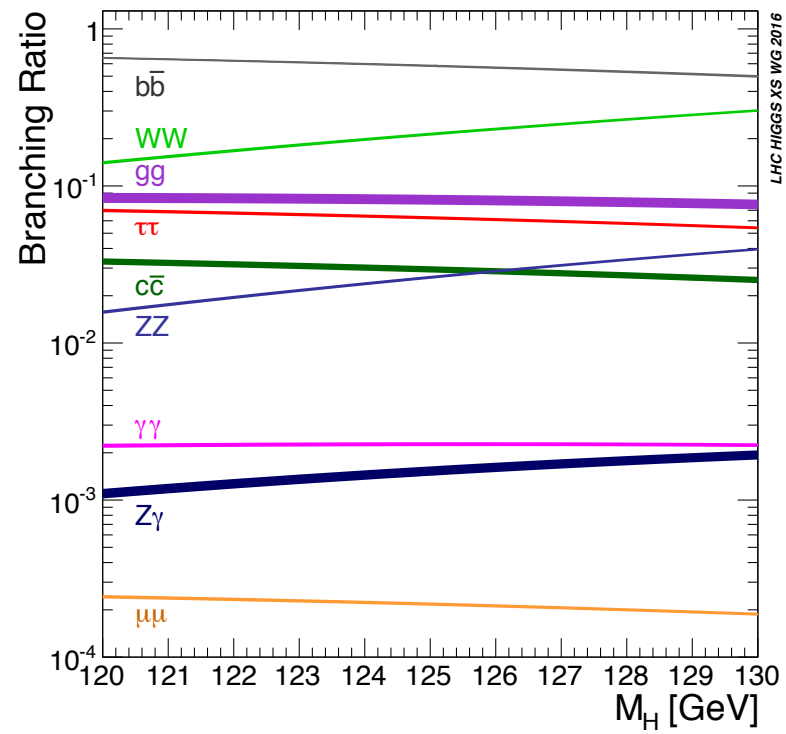


Vector Bosons



Top-quark pair

Higgs Decay Modes



Overview

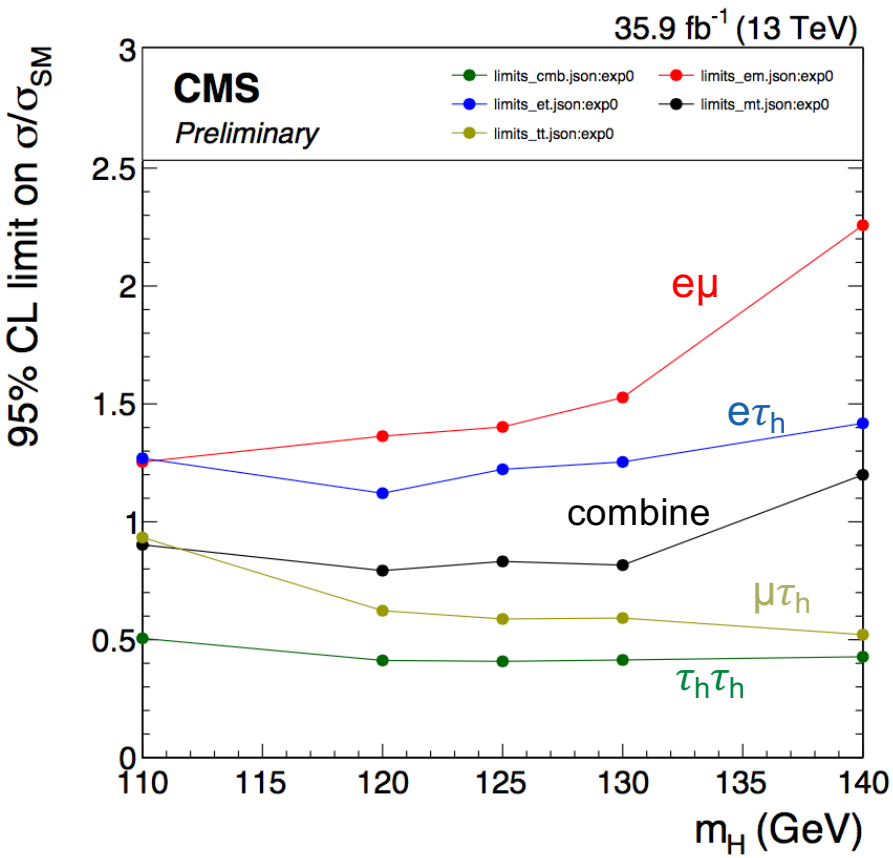
- SM $H \rightarrow \tau\tau$ is very promising channel to study the Yukawa Coupling to leptons
- Higher event rate compared to other Higgs leptonic decays
- $H \rightarrow \tau\tau$ decays with branching ratios (BR)

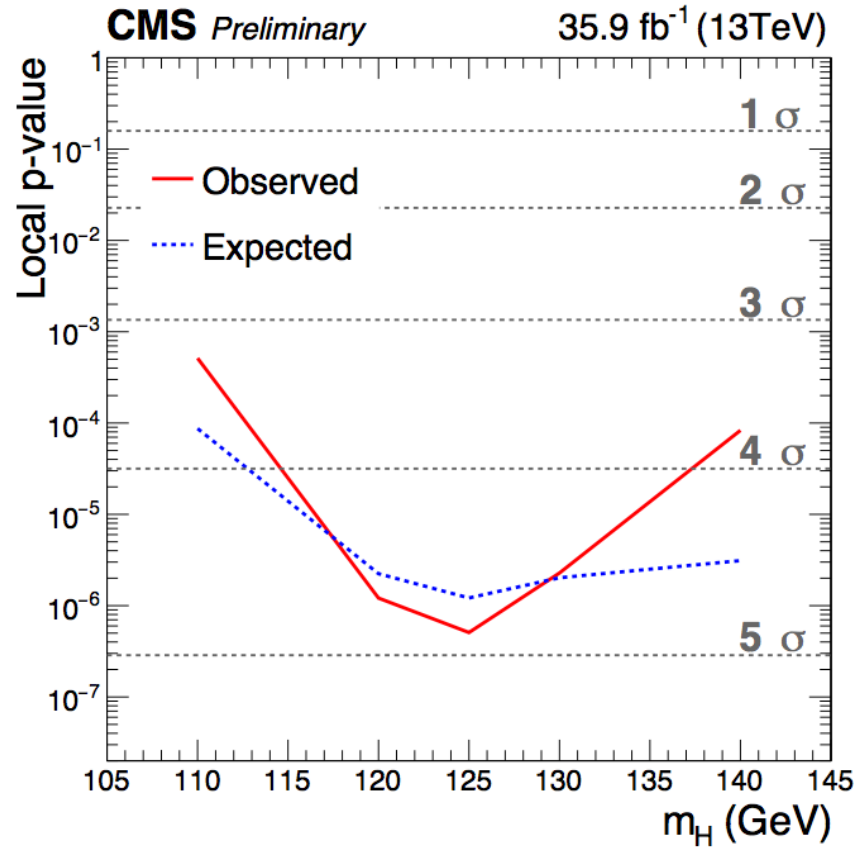
$\tau_e\tau_{had}$	23%	Hadronic decays
$\tau_\mu\tau_{had}$	23%	
$\tau_{had}\tau_{had}$	42%	
$\tau_e\tau_\mu$	6%	Leptonic decays
$\tau_\mu\tau_\mu$	3%	→ Challenge: Low sensitivity due to high Drell-Yan (DY) background
$\tau_e\tau_e$	3%	Leptonic decays

- In CMS Run I, "obtained evidence for $H \rightarrow \tau\tau$ decay at **3.2 sigma**" [JHEP 05 (2014) 104] with all six decay modes and together CMS and ATLAS observed **5.5σ** [JHEP 08 (2016) 045]

Run II result in other H→ττ decay channels

Expected limits in $\tau_h\tau_h$, $e\tau_h$, $\mu\tau_h$, eμ channels **HIG-16-043**





$\tau_h\tau_h$ is most sensitive channel

Expected significance 4.7σ
Observed significance 4.9σ

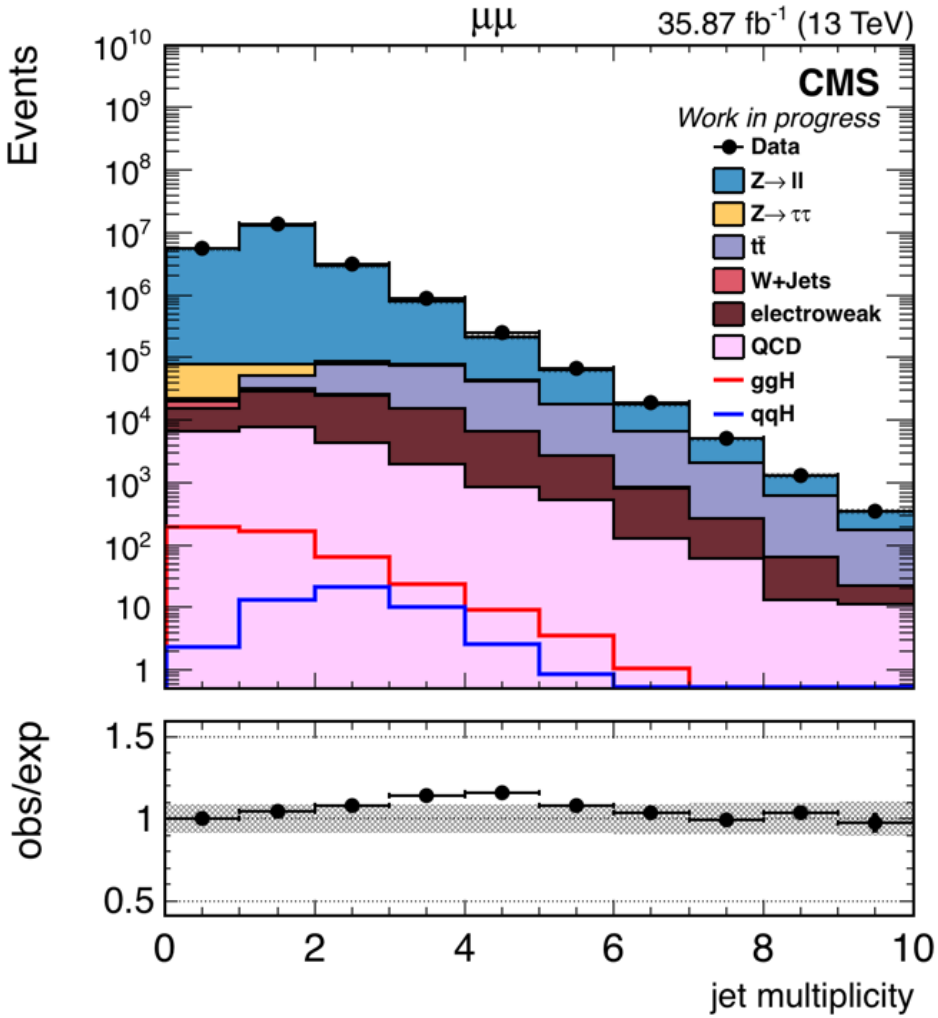
Run II: SM $H \rightarrow \tau\tau \rightarrow \mu\mu$ analysis (2016) Event selection

- $H \rightarrow \tau\tau \rightarrow \mu\mu$ analysis is performed using full 2016 data with
  $\sqrt{s}$ = 13TeV, $\int \mathcal{L}$ dt = 35.87fb^{-1} and 25ns bunch crossing

- **Single Muon dataset** used with single-muon trigger with isolated muon and p_T > 24GeV (**HLT_IsoMu24_V)**

- For this channel, **two muons** have to satisfy the following conditions:
  - p_T > 10 GeV and |η| < 2.4
  - Medium Particle Flow (PF) muon identification criteria
  - Leading muon has p_T > 25 GeV and matched to High Level Trigger (HLT) muon object within $\triangle R < 0.5$
  - Two muons should have opposite charges
  - Visible mass m_{vis}>20 GeV

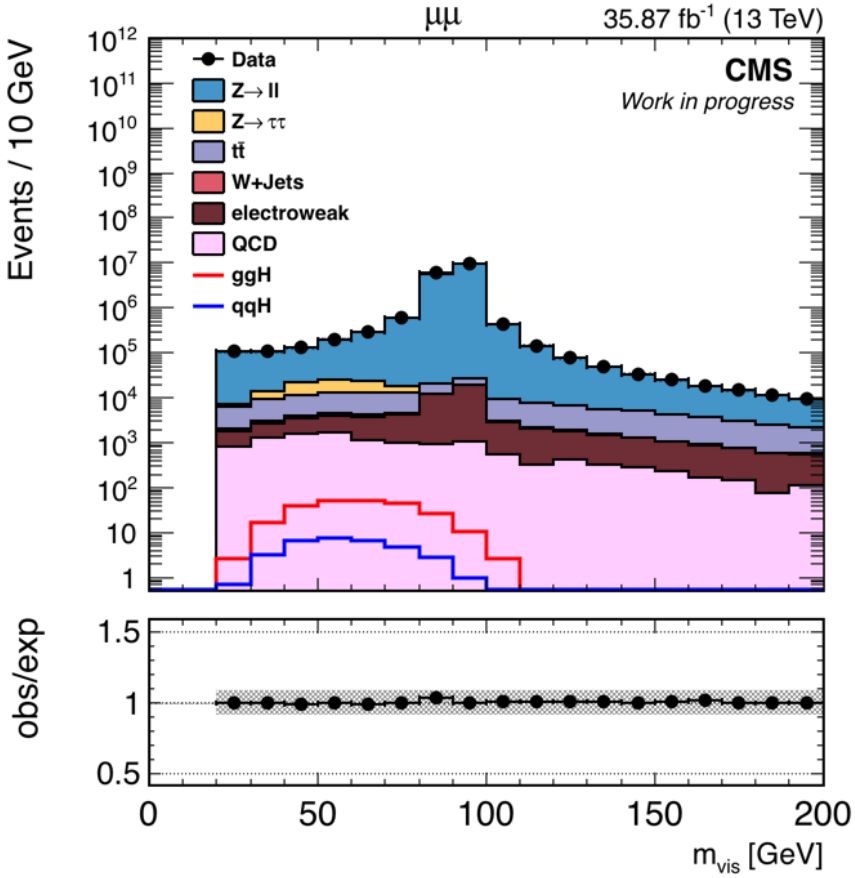
Event categorization



- 3 events categories are considered for final signal extraction
- **0jets**
  - Targets the gluon gluon fusion (ggH)
- **boosted**
  - Targeting ggH events with the Higgs recoiling against an additional jet and qqH events that fail the di-jet cut
- **VBF**
  - Targeting the qqH process via di-jet cut

Background estimation and corrections

Visible di-lepton mass ($m_{\ell\ell}$)



QCD, shape is derived from data-driven method

Corrections applied to MC

- PileUp reweighting
- Lepton identification/isolation scale factors
- Trigger scale factors

$Z\to\ell\ell$, most dominating background: Z-recoil correction and DY reweighting (p_T,m,η) are applied

$Z\to\tau\tau$, other main background: Z-recoil correction and DY reweighting (p_T,m,η) are applied

$t\bar{t}$, derived from MC and top p_T reweighting applied

Electroweak, diboson + single top

W+jets, Z-recoil correction is applied

Boosted decision trees (BDT)

- Performed multivariate analysis using BDT method separately for 3 jet categories to discriminate the DY background from the Higgs signal samples ggH and qqH

- Following variables are used in BDTs
  - **η_{dimuon}**
    The pseudorapidity of the dimuon system
  - **$p_T(2\mu)/\ (p_T(\mu^+)+p_T(\mu^-))$**
    The ratio of the transverse momentum of the dimuon system to the scalar sum of positive and negative muon momenta
  - **E_T^{miss}**
    The missing transverse energy
  - **$\Delta\Phi(\mu^+,\ E_T^{miss})$**
    The azimuthal angle between the μ^+ and missing momentum in the transverse plane

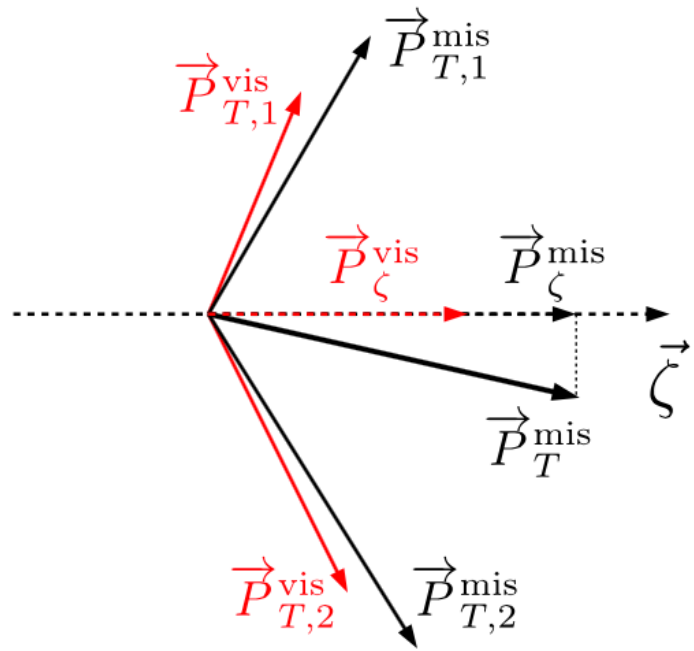
Boosted decision trees (BDT)

- **$\cos(\theta^*)$**

The polar angle of the μ^+ in the rest frame of the dimuon system

- **D_ζ**

This variable is defined as the difference of the projection of the visible transverse momentum of the τ decay products plus missing transverse momentum and visible transverse momentum of the τ decay products on the ζ axis which is the center line between visible momenta



- **p_T^{tot}** (only for boosted category)

Total transverse momentum of the system

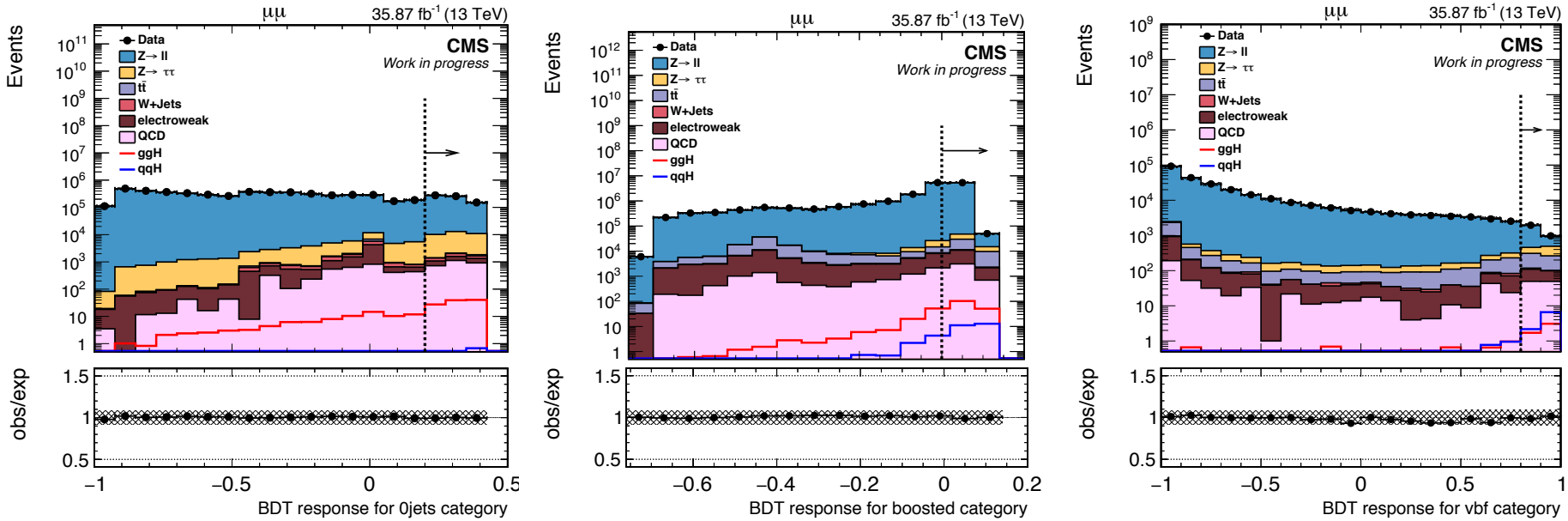
- **m_{jj}** (only for VBF category)

Dijet mass

Figure source **HIG-16-043**

BDT response for each category

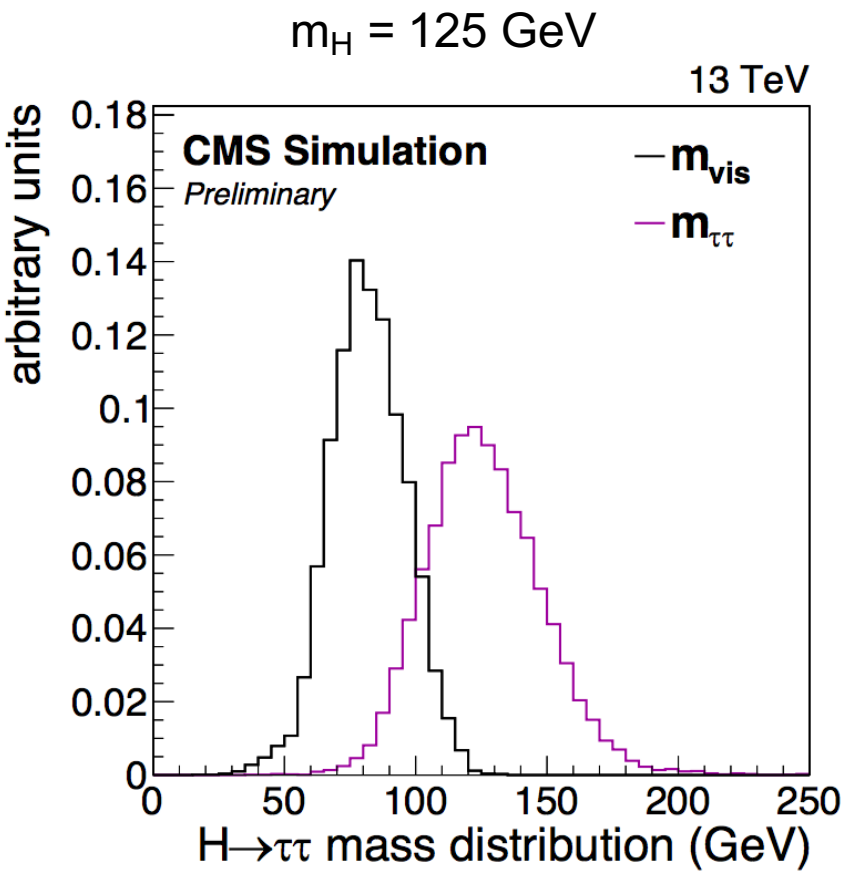
0Jet **boosted** **VBF**



Loose initial cuts on the BDT response are applied to select events with enhanced S/√B as well as to reduce the overall processing time for the time-consuming reconstruction of the di-tau mass using a secondary vertex fit (SVfit) algorithm

Event Category	0jet	boosted	VBF
BDT cut	>0.2	>0.0	>0.8

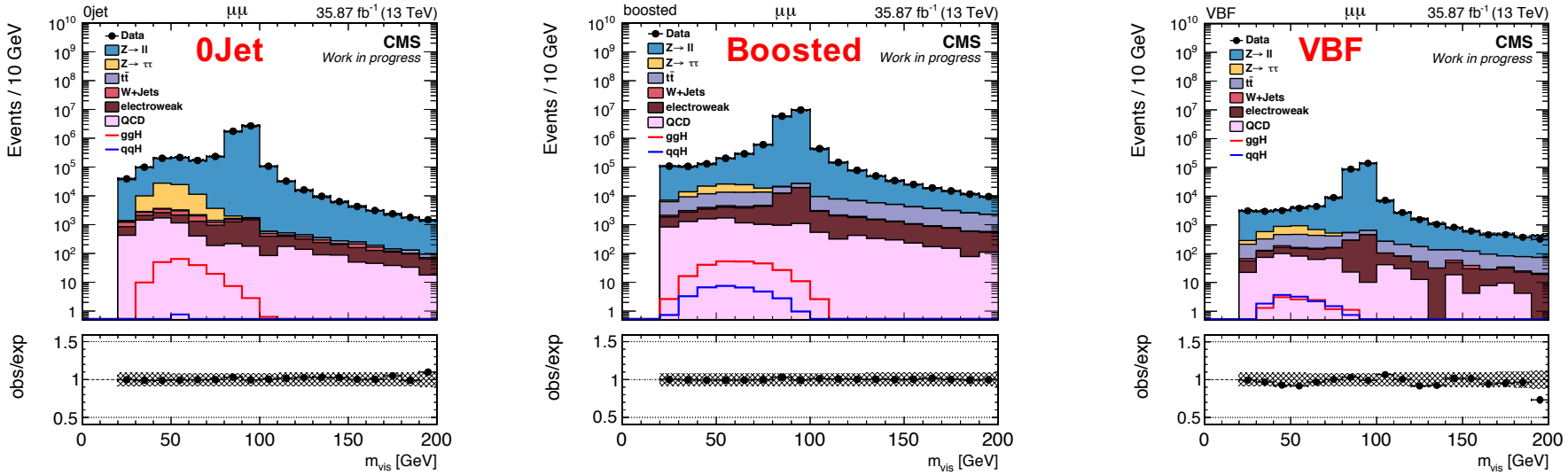
Signal extraction method



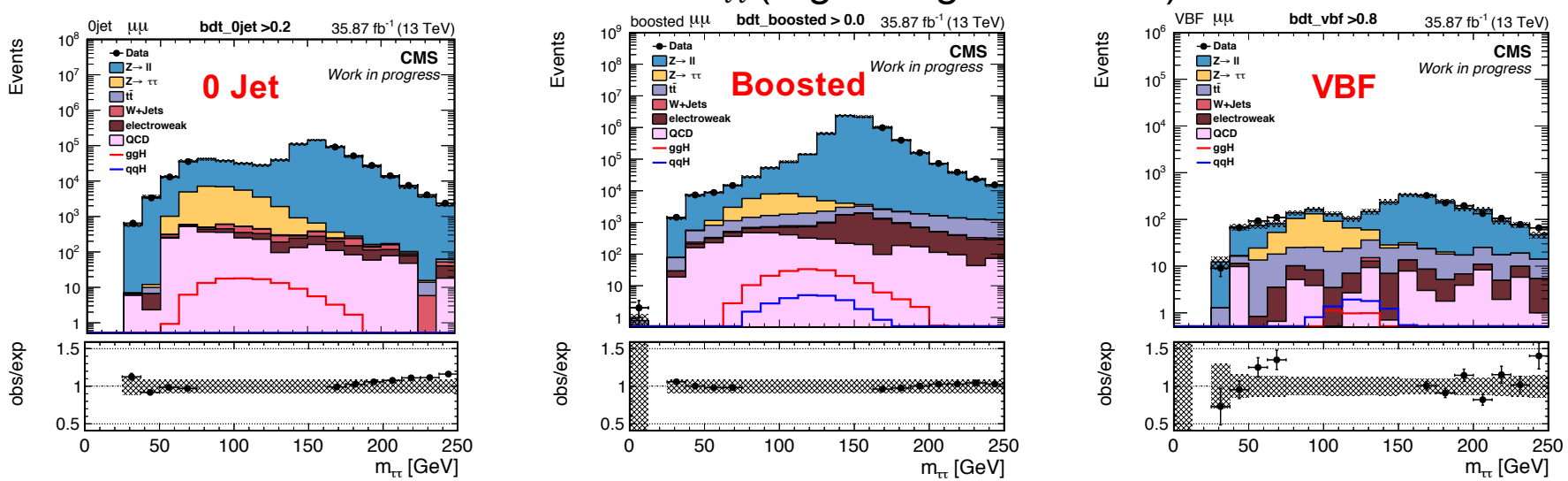
- Di-tau mass ($m_{\tau\tau}$) is reconstructed using **S**econdary **V**ertex **Fit** (SVFit)
  - It is a likelihood-based estimation of the parent boson mass
  - Inputs used for the calculations are: MET, MET uncertainties and four vectors of each tau candidate
- Signal is extracted using 2D method in the plane of reconstructed SVFit mass $m_{\tau\tau}$ and visible mass $m_{\ell\ell}$

Mass distributions

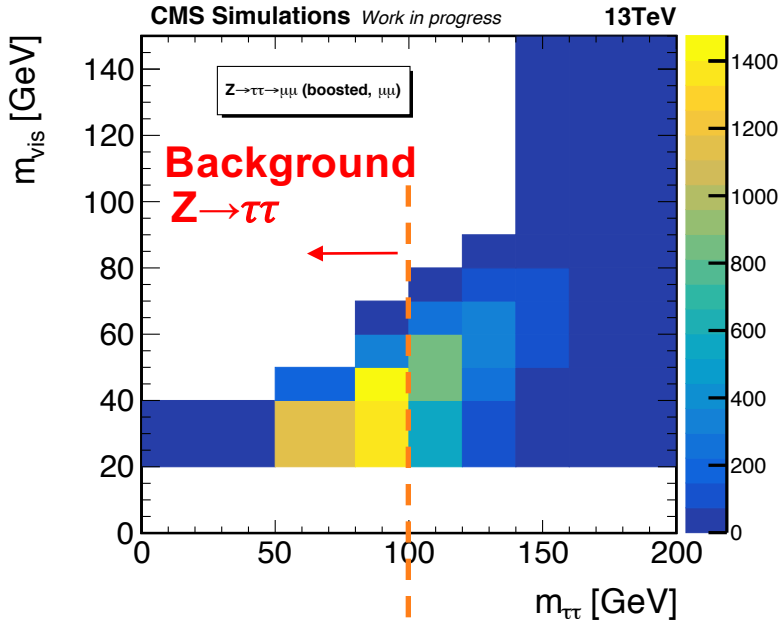
Visible mass $m_{\ell\ell}$



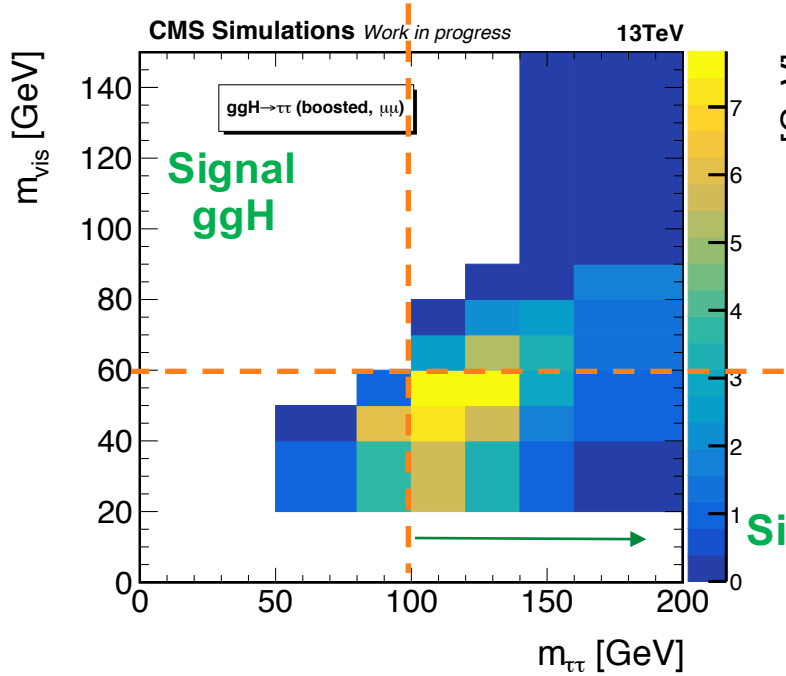
SVFit mass $m_{\tau\tau}$ (Signal region blinded)

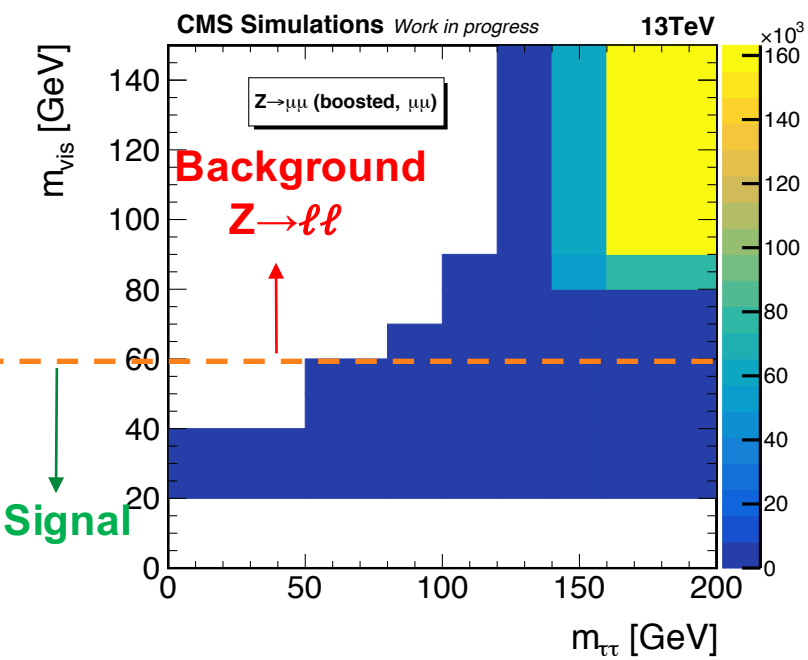


boosted category



2D mass distribution for signal extraction in boosted category with bdt_boosted >0.073

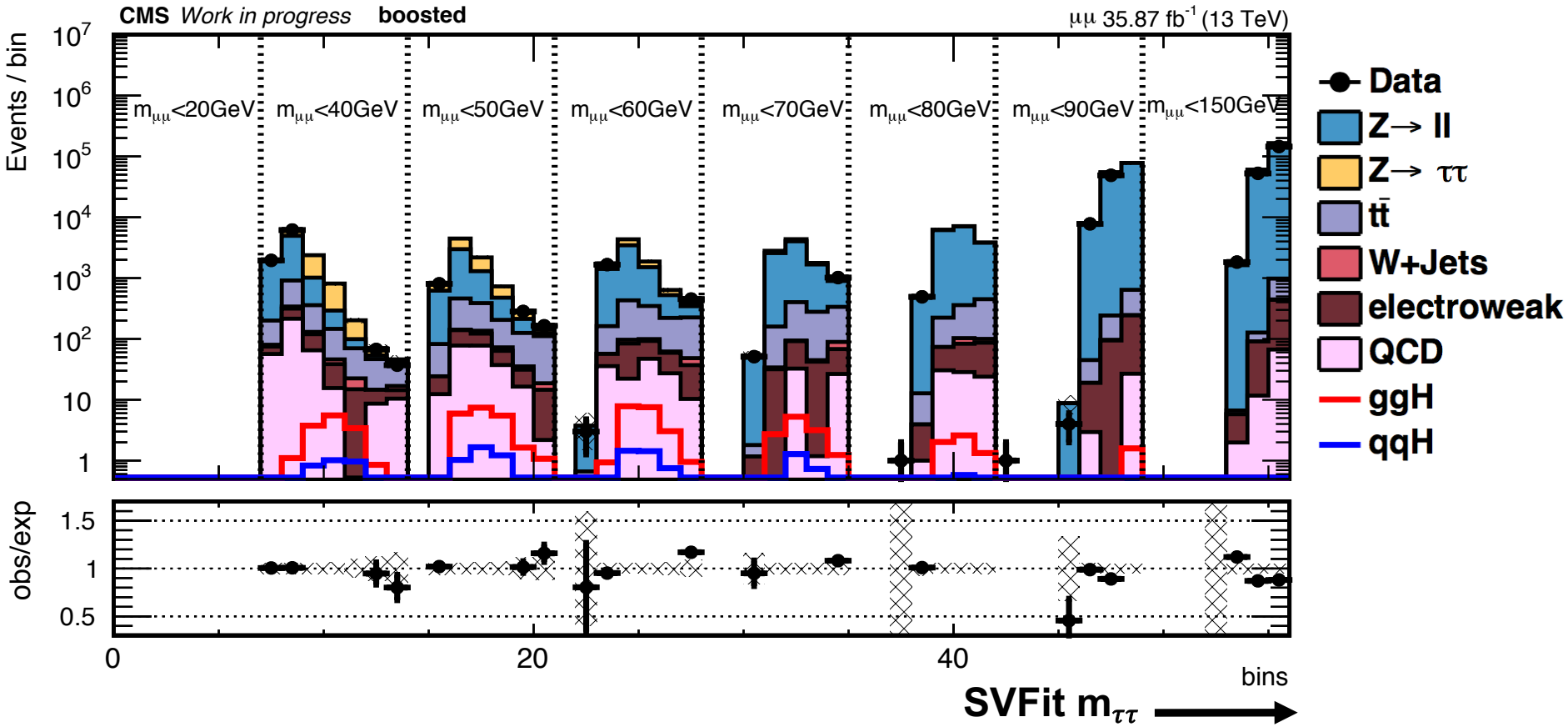




Di-tau mass unrolled in visible mass

boosted category

$BDT_{boosted}$ > 0.073



Signal region blinded

Uncertainty model

Following normalization and shape uncertainties are used for calculating limits

Normalization:

- Luminosity
- Identification/isolation efficiencies
- Background (statistical uncertainties on side band)

Shape:

- Muon p_T
- Top p_T reweighting
- DY reweighting
- b-tag efficiency
- Jet energy scale
- Missing transverse energy response

Expected limits are calculated by maximizing the likelihood function for each bin of the unrolled mass distribution.

Summary

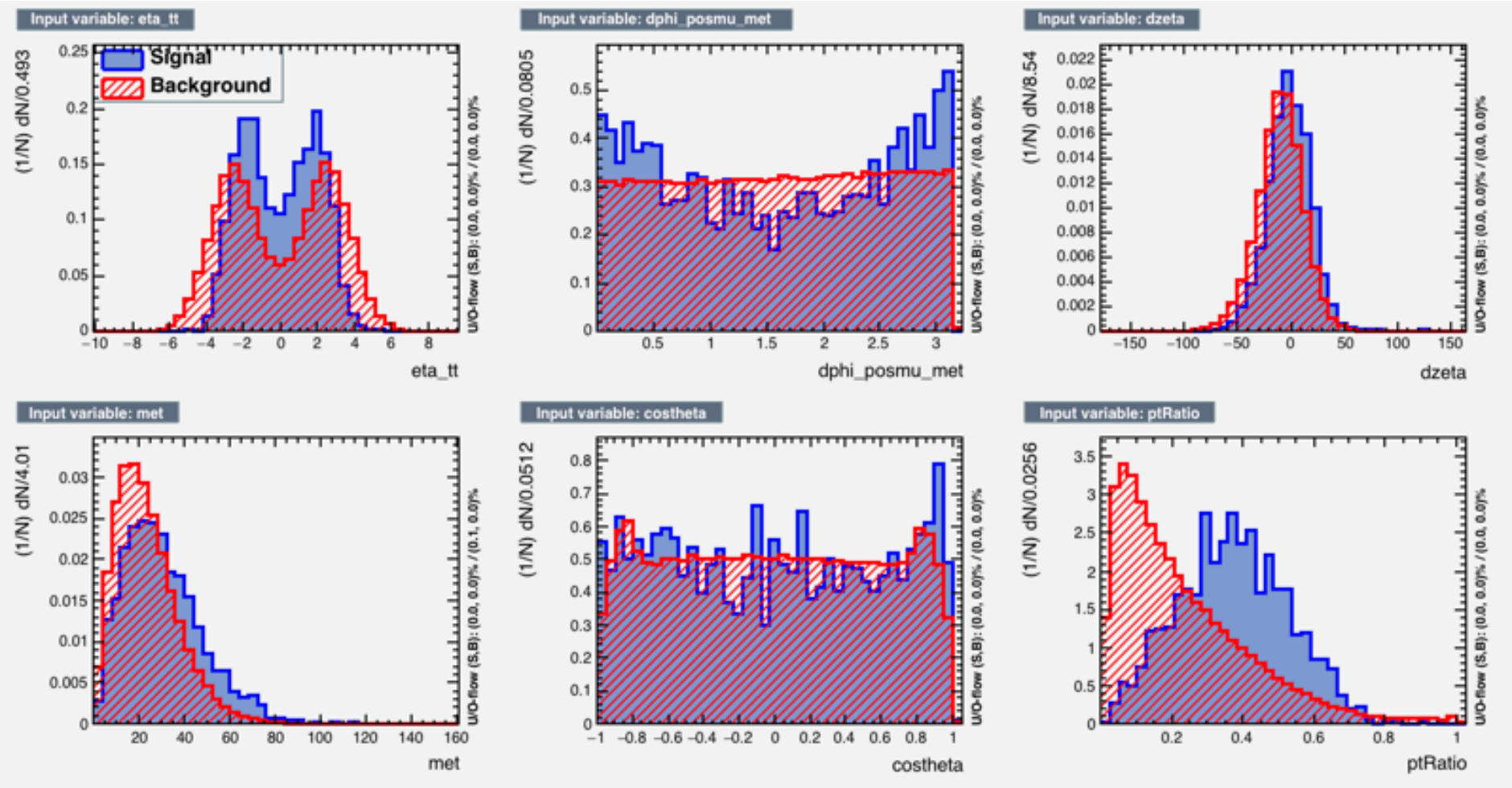
- Successfully implemented the BDT method to suppress dominating DY background in each event category

- In this decay mode, the VBF category is most sensitive of 3 categories to observe the Higgs coupling followed by boosted and 0jet category

Thank you!!

BackUp

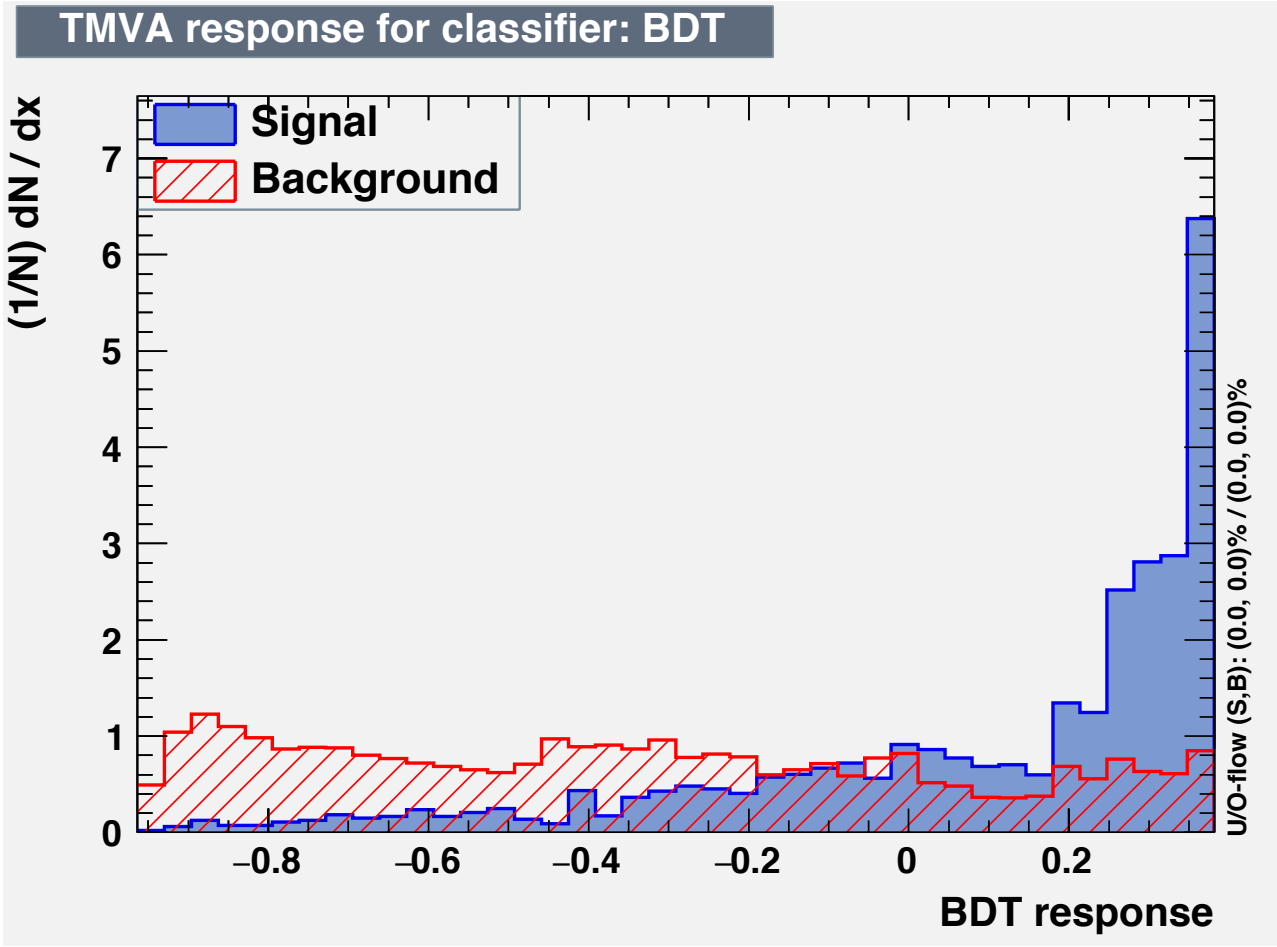
Variables used in 0jet BDTs



Signal➔ ggH

Background ➔ Z→ℓℓ and Z→ττ

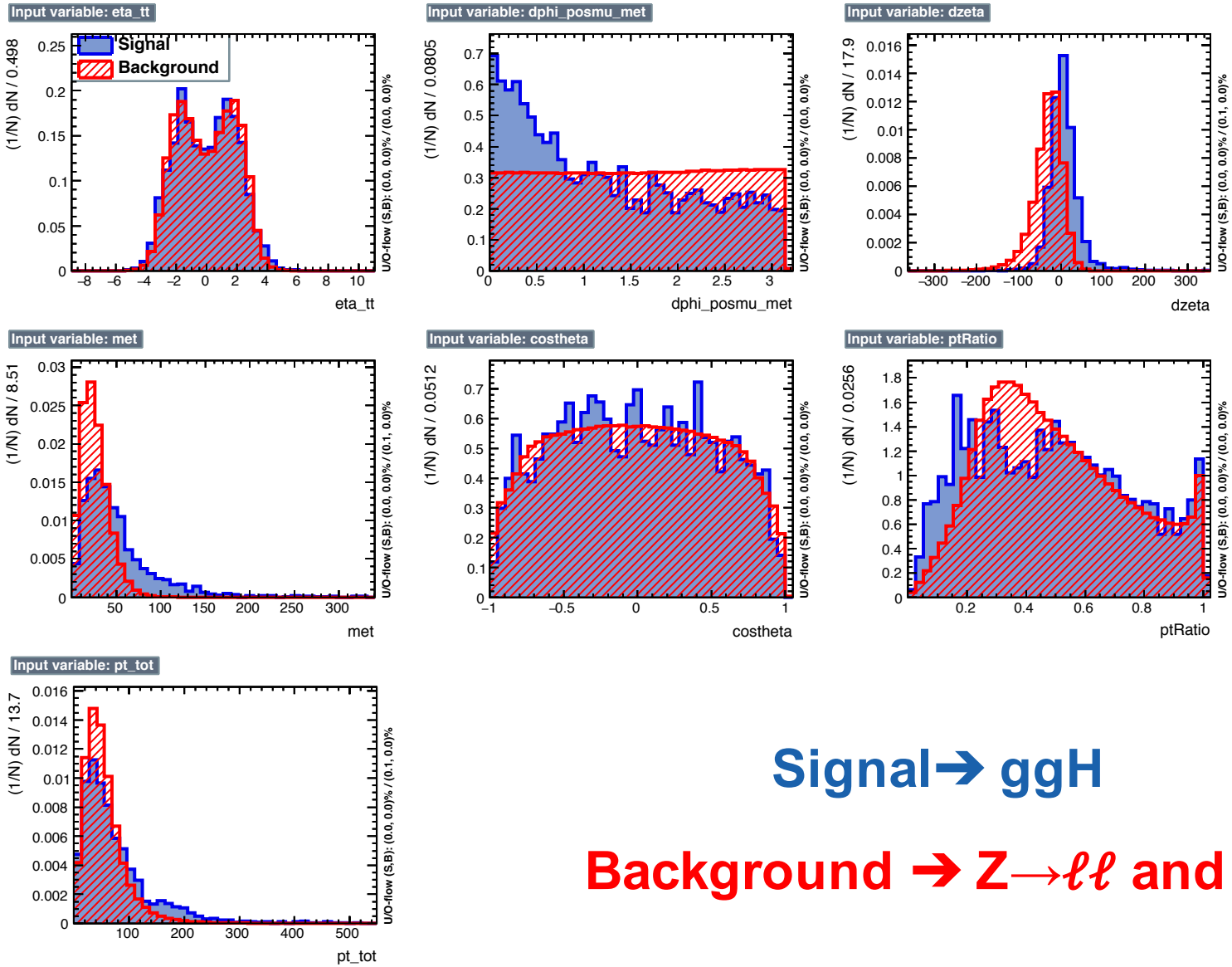
BDT response in 0jet Category



Background ➔ Z→ℓℓ and Z→ττ

Signal➔ ggH

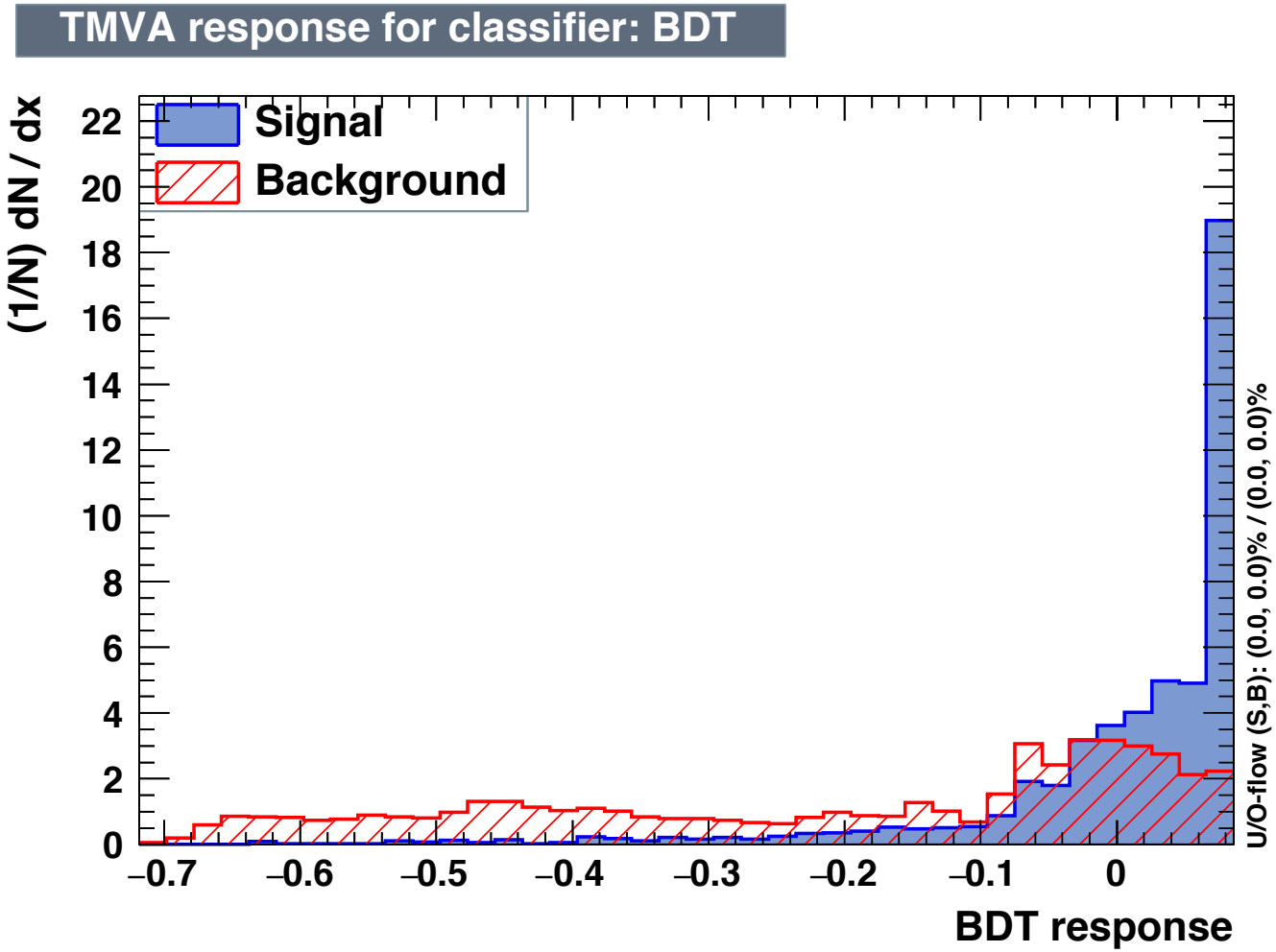
Variables used in boosted BDTs



Signal → ggH

Background → $Z \to \ell\ell$ and $Z \to \tau\tau$

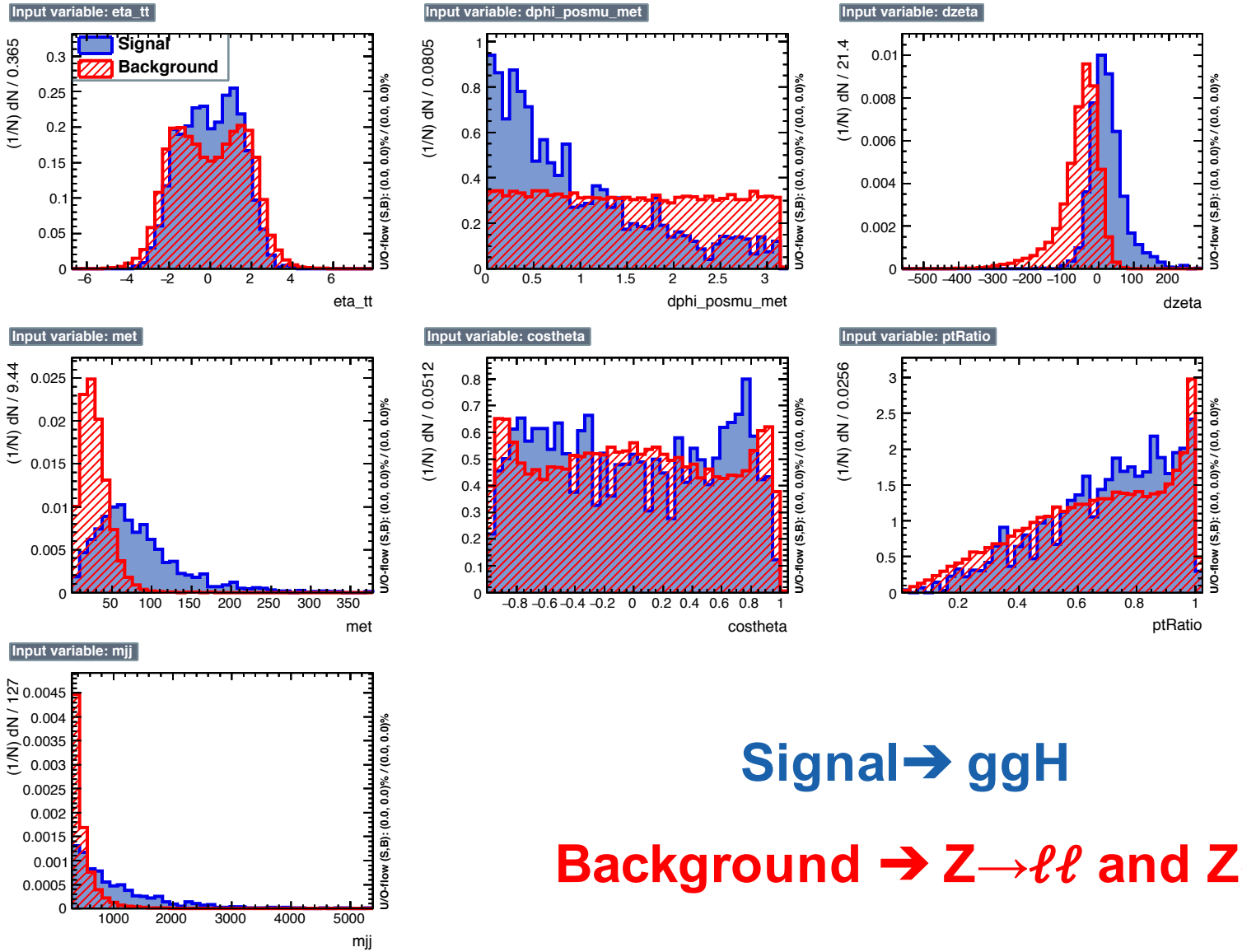
BDT response in Boosted Category



Background ➔ $Z \to \ell\ell$ and $Z \to \tau\tau$

Signal ➔ ggH

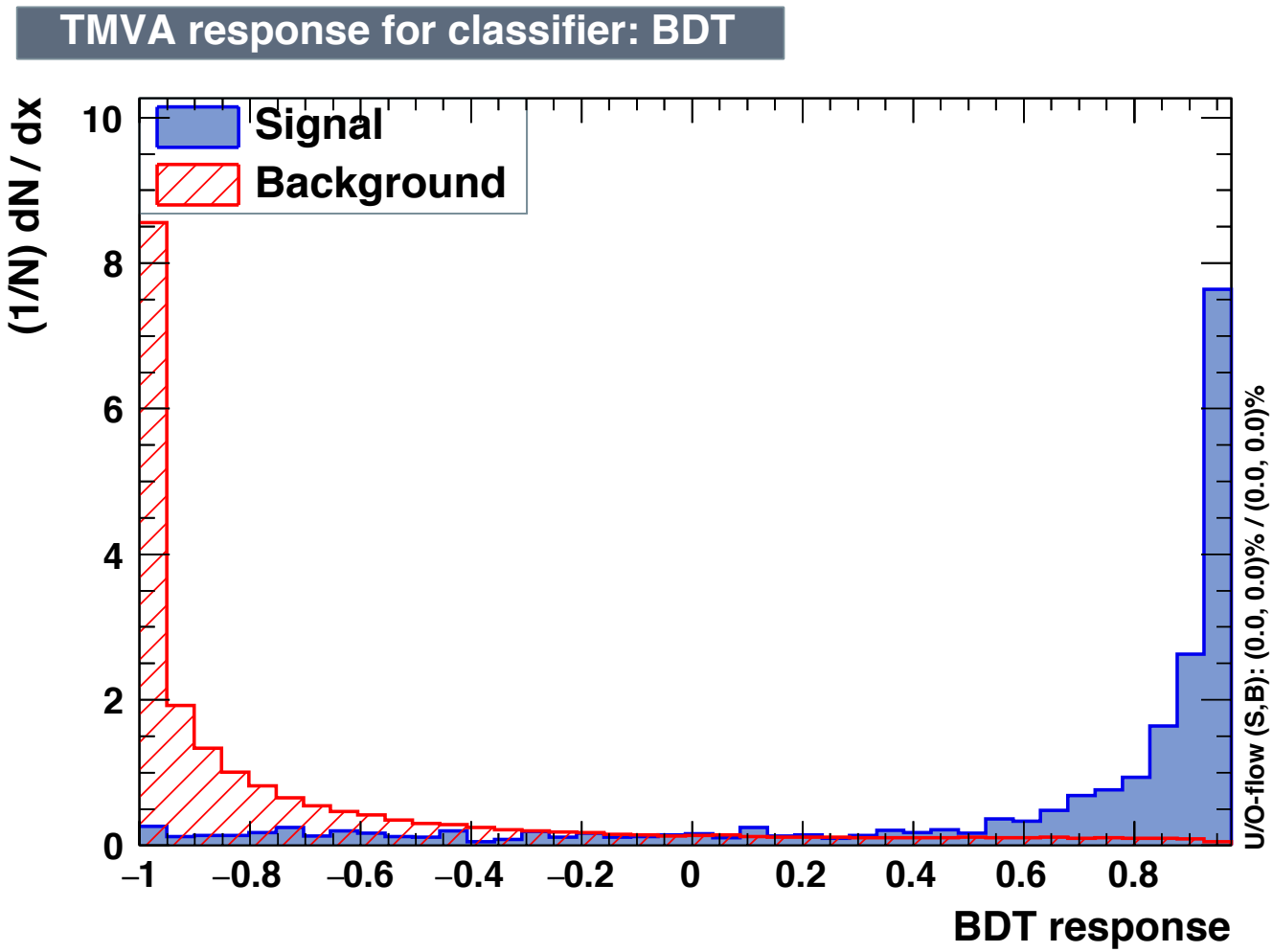
Variables used in VBF BDTs



Signal → ggH

Background → $Z \to \ell\ell$ and $Z \to \tau\tau$

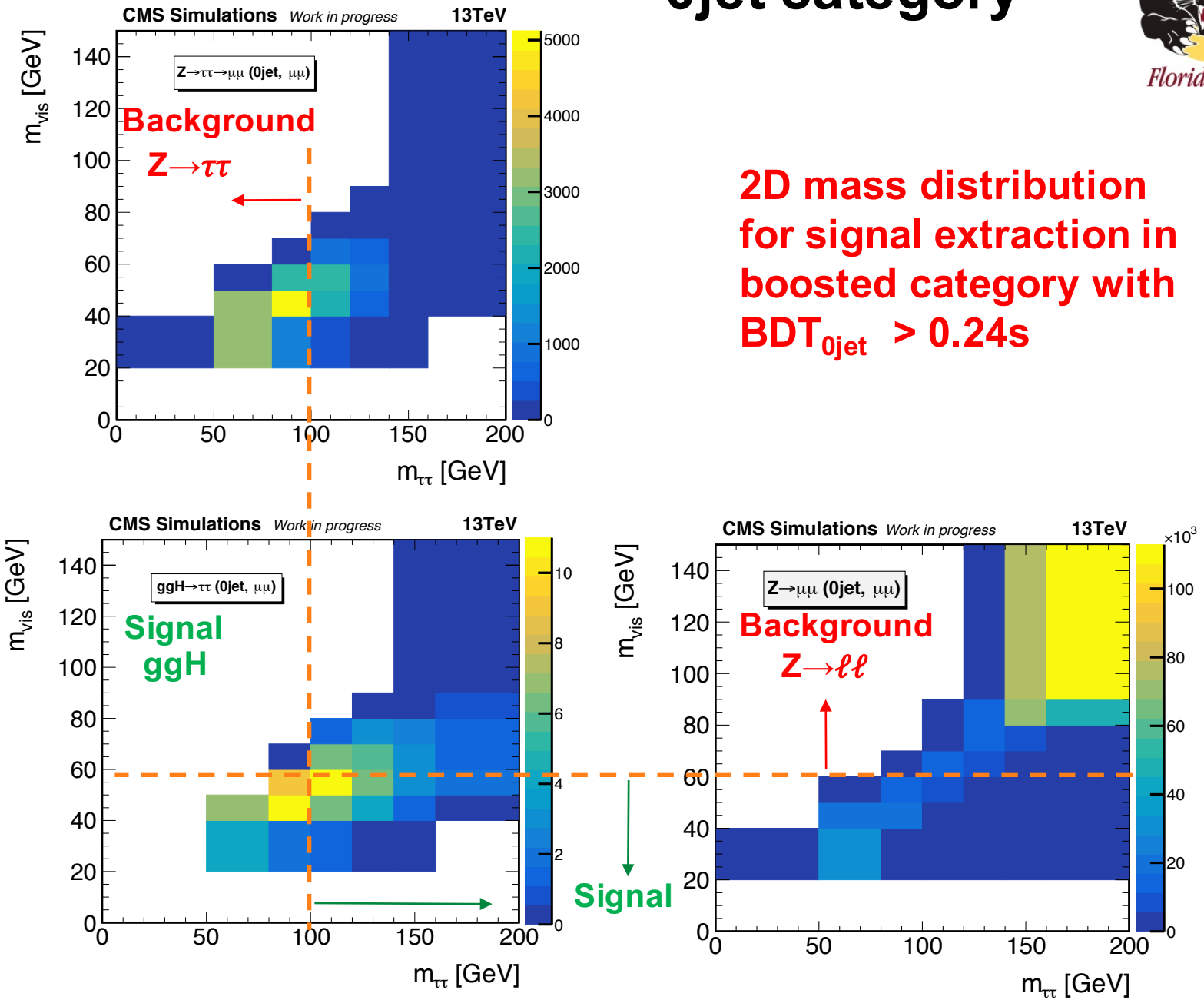
BDT response in VBF Category



Background ➔ Z→ℓℓ and Z→ττ

Signal➔ ggH

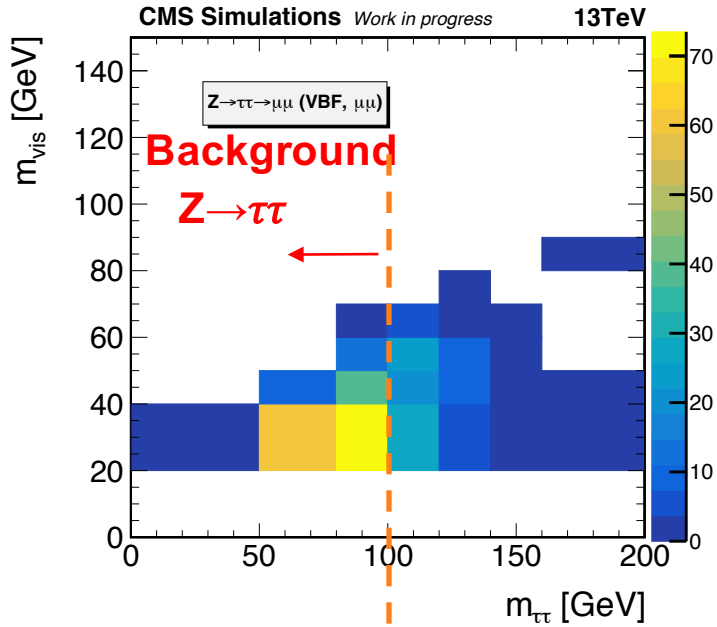
0jet category

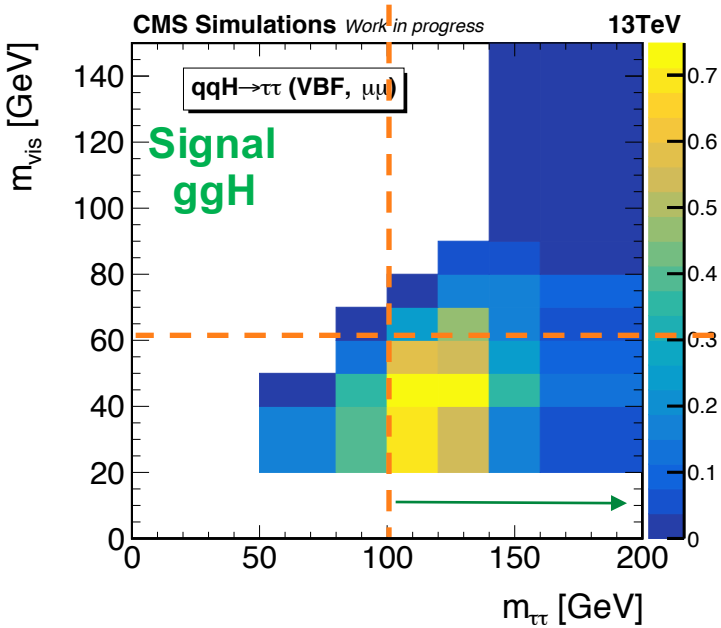


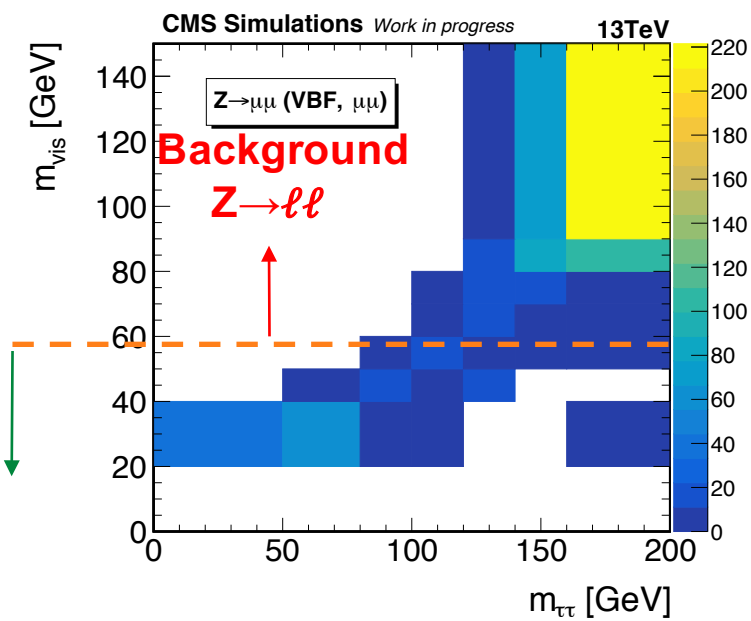
2D mass distribution for signal extraction in boosted category with BDT_{0jet} > 0.24s

VBF category

2D mass distribution for signal extraction in boosted category with $BDT_{VBF} > 0.86$



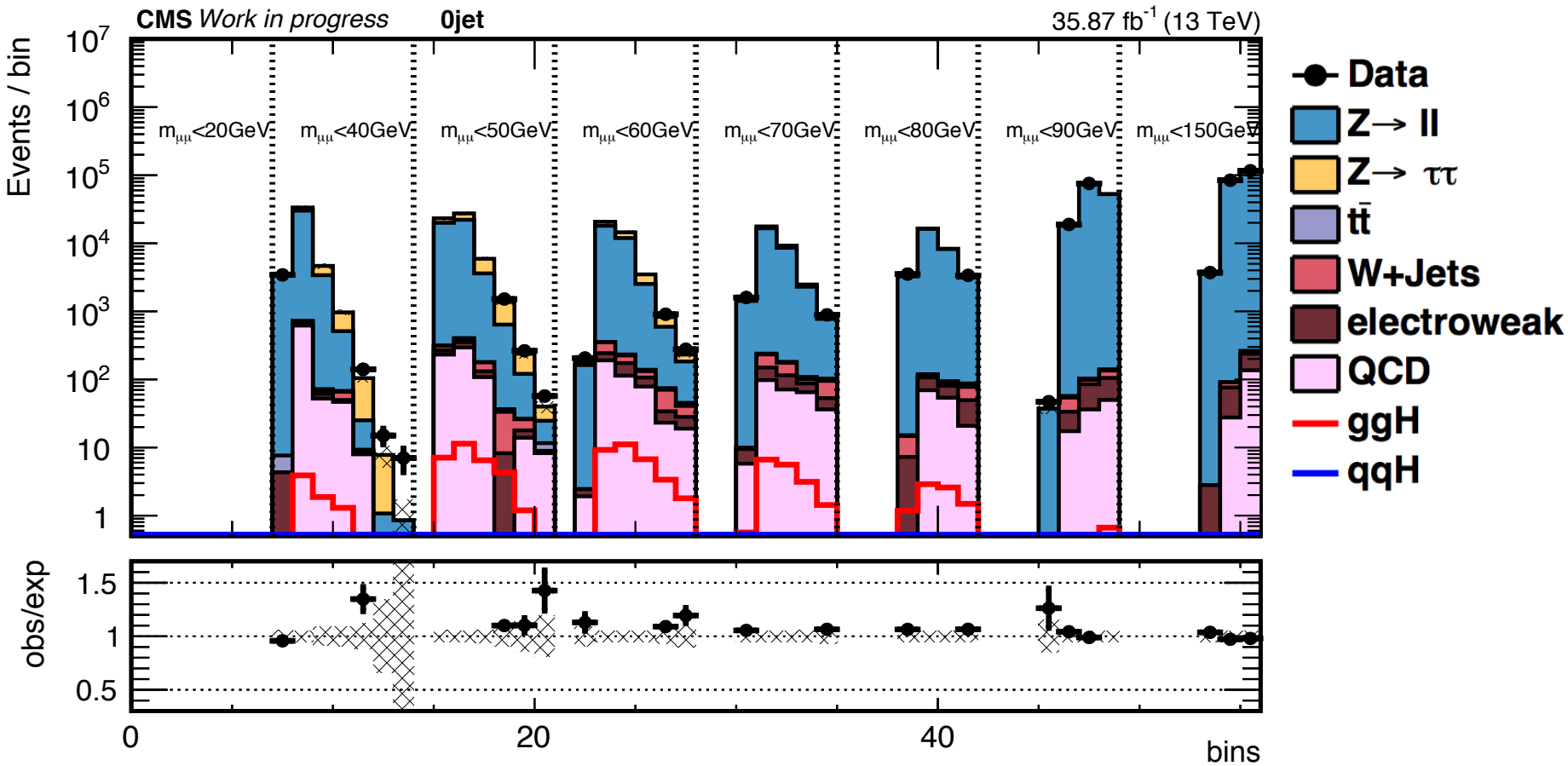




Di-tau mass unrolled in visible mass

BDT_{0jet} >0.24

0jet category



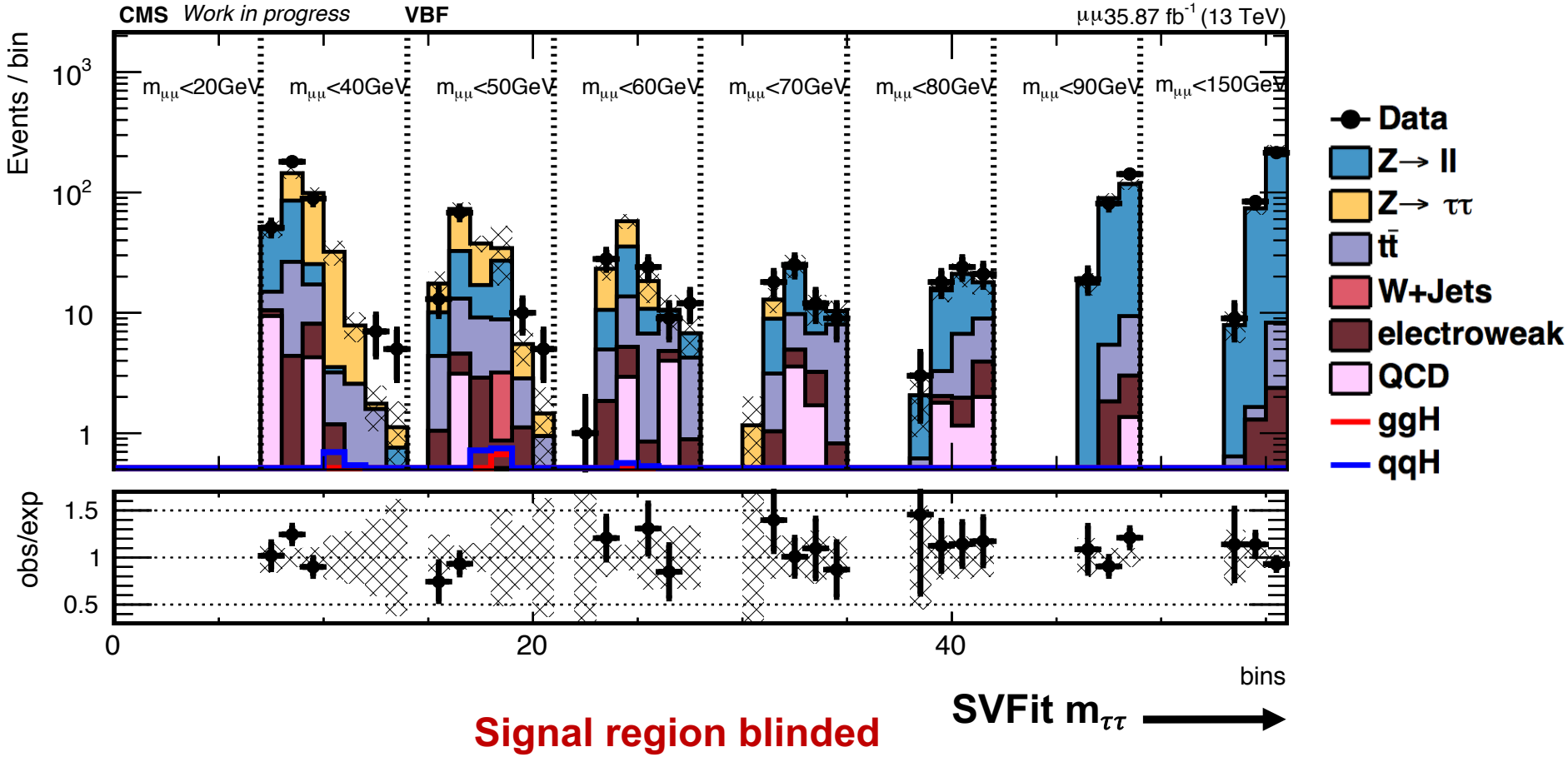
Signal region blinded

SVFit $m_{\tau\tau}$ →

Di-tau mass unrolled in visible mass

VBF category

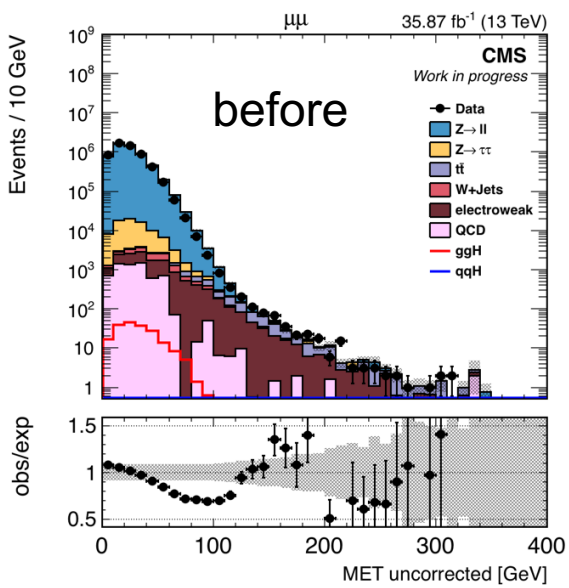
BDT_{vbf} >0.86

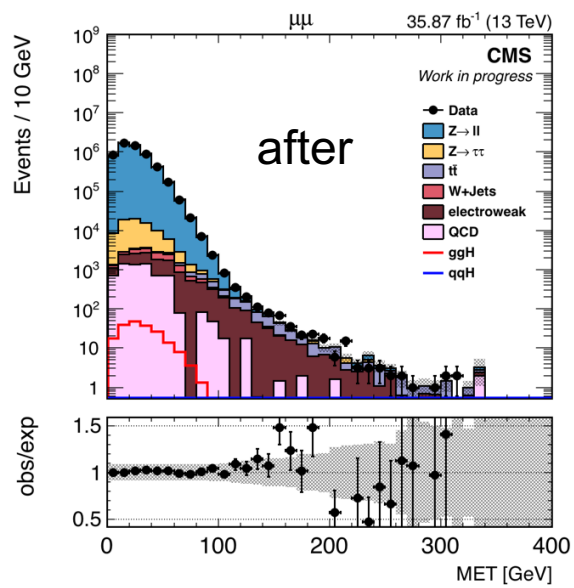


Signal region blinded

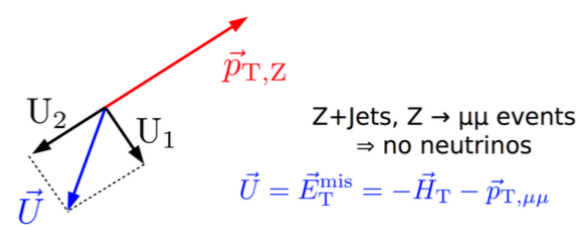
MET recoil correction

- Correct of the mismodelling of MET in events where no genuine MET
  - Correction derived in Z(μμ) events by measuring two component of the hadronic recoil as a function of Z p_T and jet multiplicity
  - Corrections applied to DY, W+Jets, VBF and ggF Higgs samples





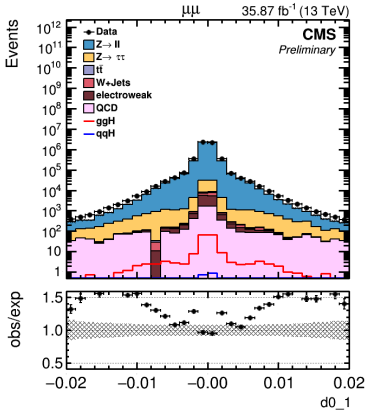
$$\vec{U} \equiv \vec{E}_T^{mis} - \sum \vec{p}_{T,\nu} = -\vec{H}_T - \vec{p}_{T,Z}$$

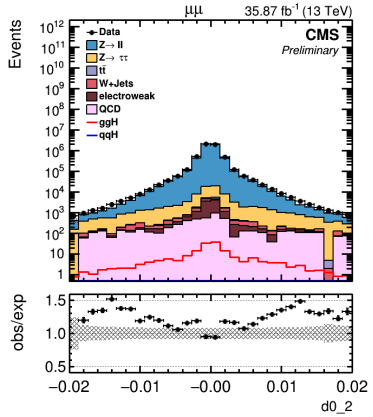


Impact parameters

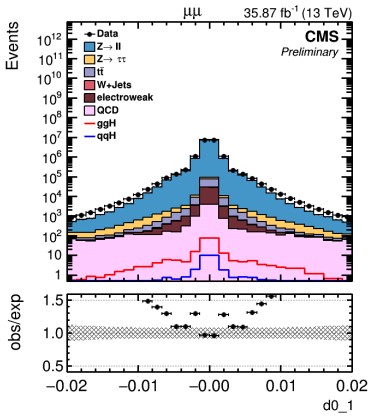
dxy

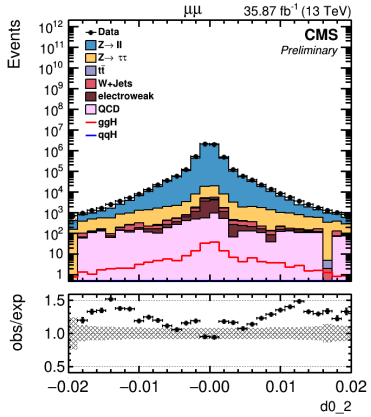
0 Jets



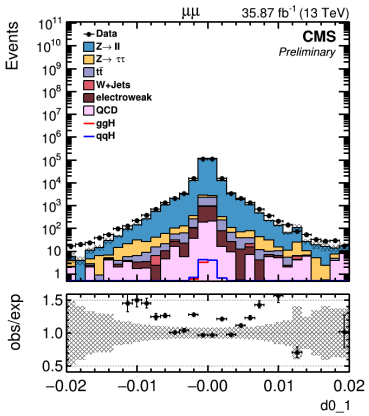


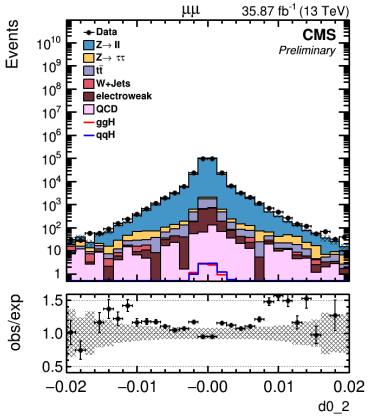
Boosted





VBF

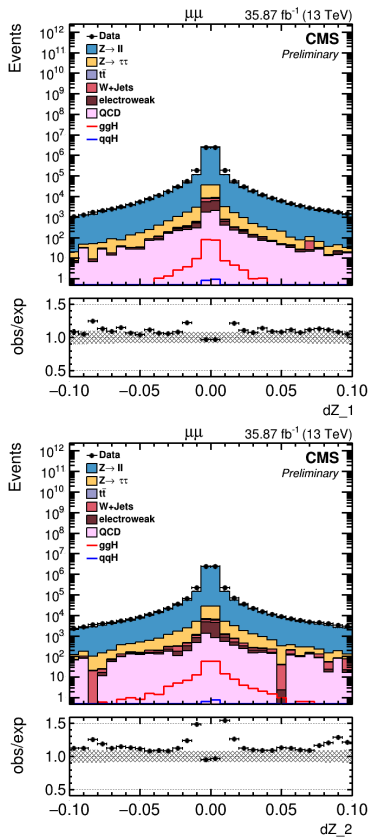




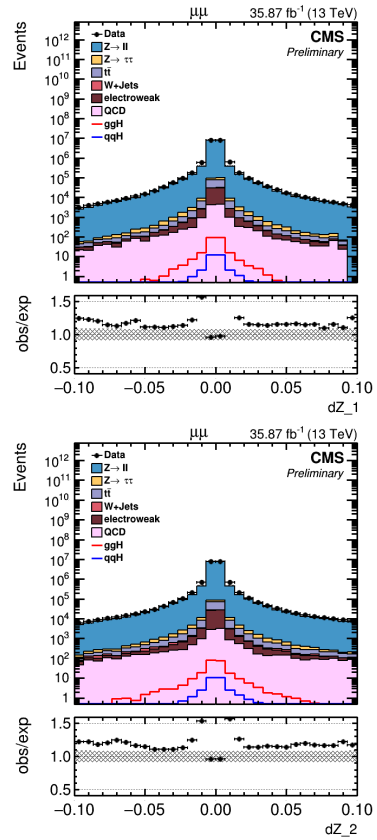
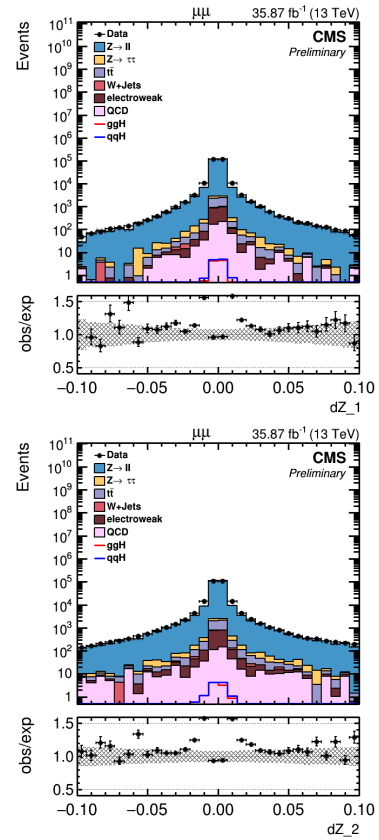
Impact parameters

dZ

0 Jets



Boosted



VBF