Higgs production via Vector Boson Fusion and decaying to a pair of b-quarks

YSF Talk

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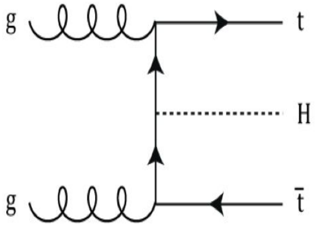
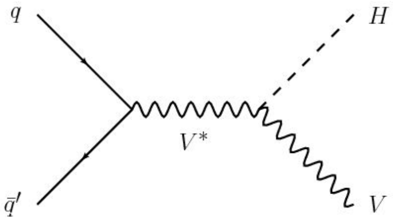
Higgs production mechanisms at the LHC

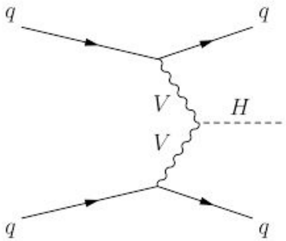
$t\bar{t}H$



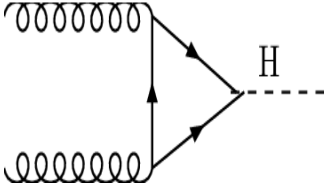
VH



VBF



ggF



Xsec: 0.5 pb | Xsec: 2.61 pb | Xsec: 3.78 pb | Xsec: 48.6 pb

Production cross section

Key features of VBF process:

Vector Boson Fusion (VBF) → sub-leading Higgs production process

→ Cross section 3.78 pb @ N^2LO QCD and NLO EWK accuracy

→ Very distinctive topology by a pair of forward-backward jets referred to as "VBF" jets with high invariant mass (m_{jj}) and high pseudo-rapidity gap ($\Delta\eta_{jj}$), VBF criteria.

Current status of VBF Higgs production

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→ Combined signal strength of VBF-H process (μ_{VBF}) :

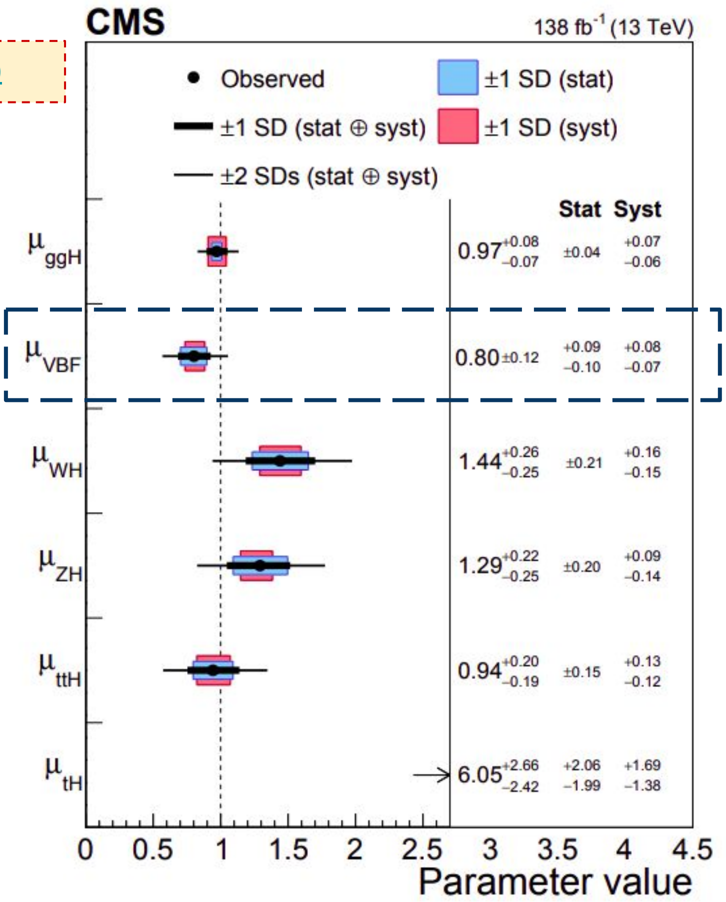
0.80 ± 0.12

→ Observed value is **> 1σ** away from the SM prediction

→ Total uncertainty is equally divided into systematics and statistics

→ All Higgs decays modes are included here **except H → bb**

→ VBFH(bb) in resolved topology is being presented here using Run-2 data



Overview of VBF H→ bb

→ Maximum BR H → bb (58%)

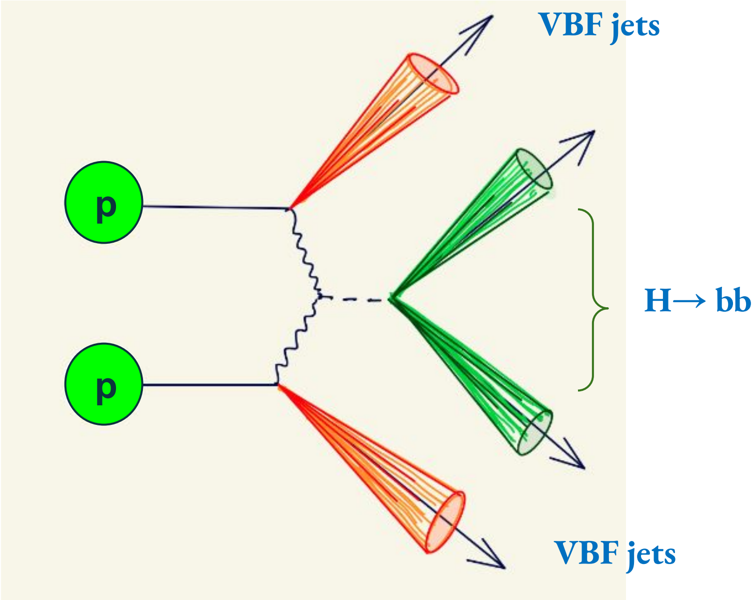
Experimentally challenging

→ Overwhelming QCD background events

Difficult to trigger the events due to extremely high production rate

→ Low signal-to-background ratio reduce the sensitivity of the analysis

→ Large resonant Z→ bb background
(signal in the higher tail of the Z peak, difficult to model)



VBF H → bb: analysis technique

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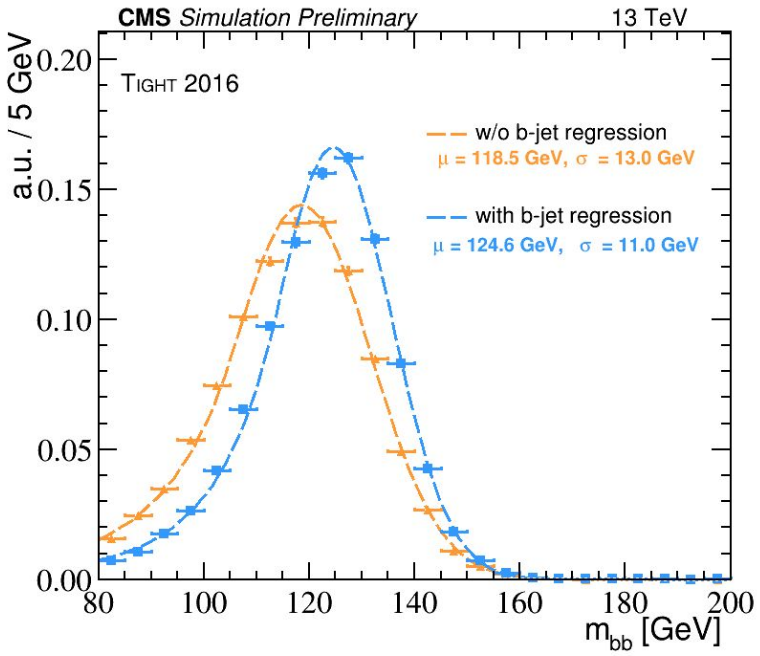
- Two dedicated high level trigger using **VBF topology and b-tagging requirements**
  TIGHT : Stringent VBF criteria with loose b-tag
  LOOSE : Loose VBF requirement with tight b-tag
  → The analysis is performed with the accumulated Run2 data of **91 fb^{-1} integrated luminosity.**

- Two highest b-tagged AK4 jets are selected as Higgs candidate

- **DNN based b-jet energy regression** [Computing and Software for Big Science 4 (2020) 10] applied to improve the mass & resolution of the m_{bb} spectrum
  [15% improvement on σ/μ of signal process]

- Two jets passing the VBF requirements [m_{jj} & $\Delta\eta$]: VBF jets.
- Multivariate techniques used to separate signal from the contributing backgrounds



Finally m_{bb} distribution has been used to extract the results

VBF H → bb : Separation of signal from background

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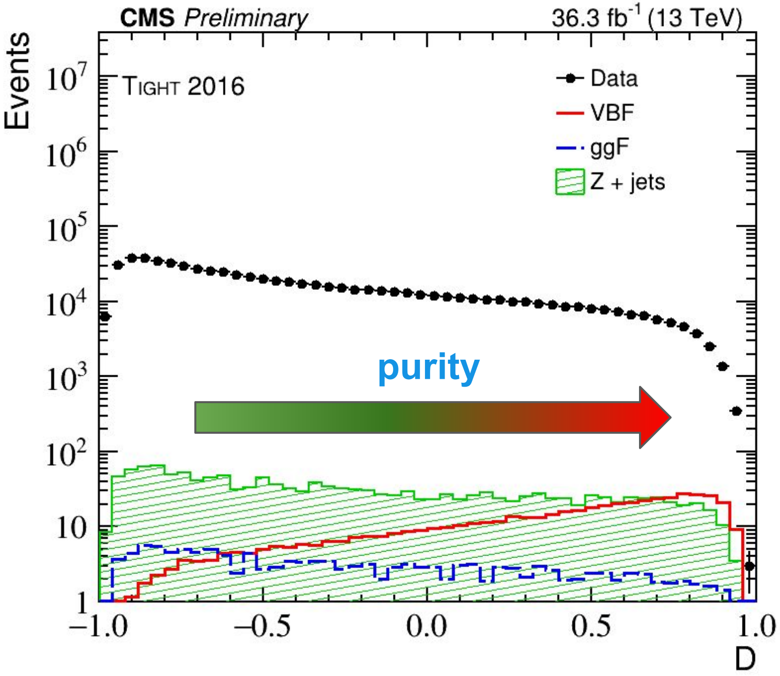
- Separate MVA trainings
  TIGHT : Binary classifier (VBF vs QCD)
  LOOSE : Multi-classifier (VBF vs ggF vs ZJets Vs QCD)

- Events are categorized based on discriminants' score (D)
  Increase the analysis sensitivity



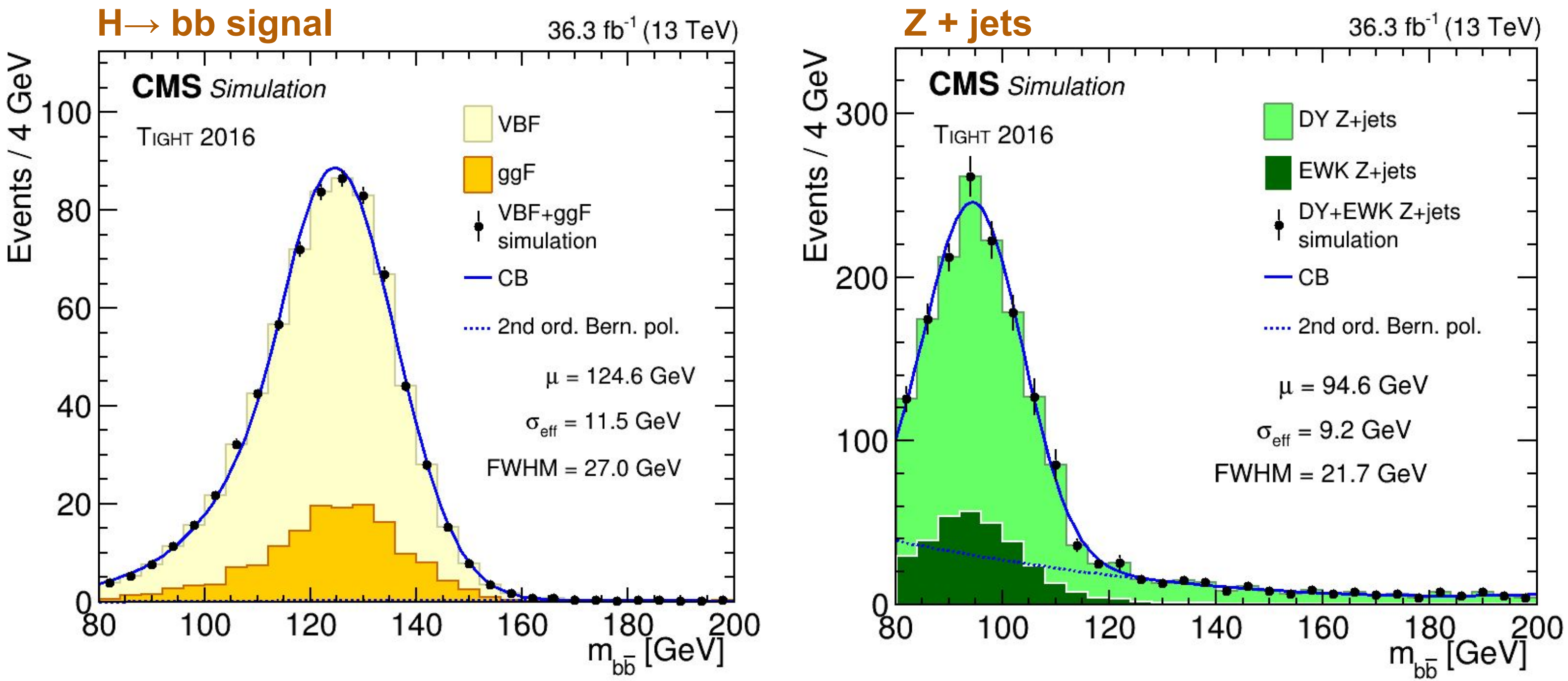
- Categories target not only VBF, but ggF and Z + jets as well
- **ggF categories** Improve sensitivity to the inclusive signal strength (ggF + VBF)
- **Zbb categories** Establish Zbb standard candle and constrain rate of the Z+jets production

- Total 18 categories
  → All categories have been used simultaneously to extract the final results

Signal and resonant Z+jets backgrounds modeling

→ The expected event yields of the signal (VBF & ggF) and resonant backgrounds of Z(bb) + jets [DY & EWK] estimated in each category from simulation by Crystal Ball function.

→ 2nd order bernstein polynomial for the higher tail (mostly for Z + jets)



VBF H → bb : continuum background fit

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→ Shape and normalization of the continuum backgrounds are derived from fit-to-data using Generic polynomial functions (F_i)

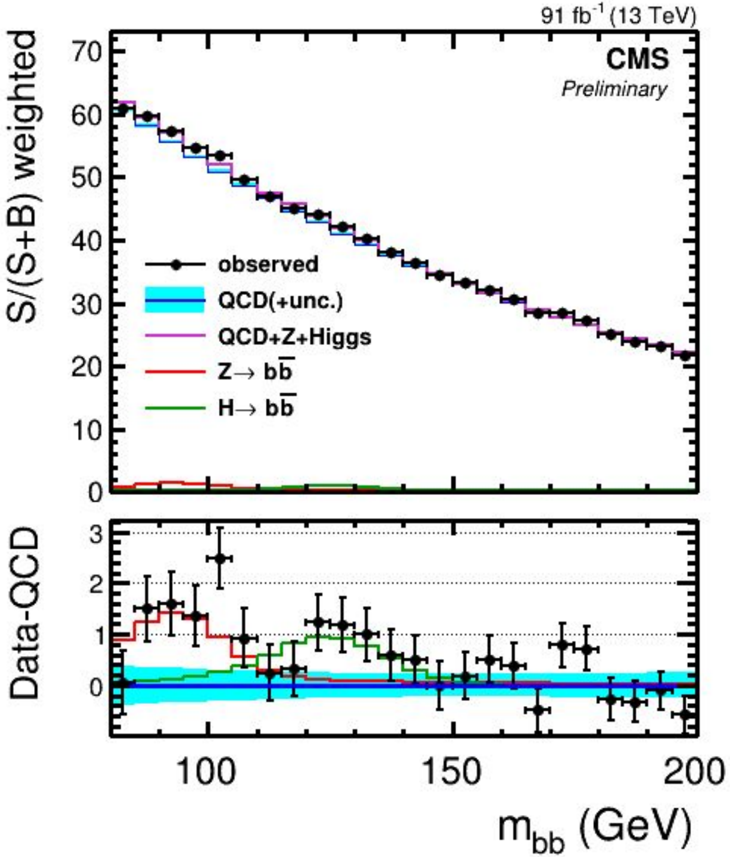
$$F_i^{QCD} = \exp\left(-b_i \cdot m_{bb}\right) \cdot \left(1 + \sum_{j=1}^{n} a_{ij} \cdot m_{bb}^{j}\right)$$

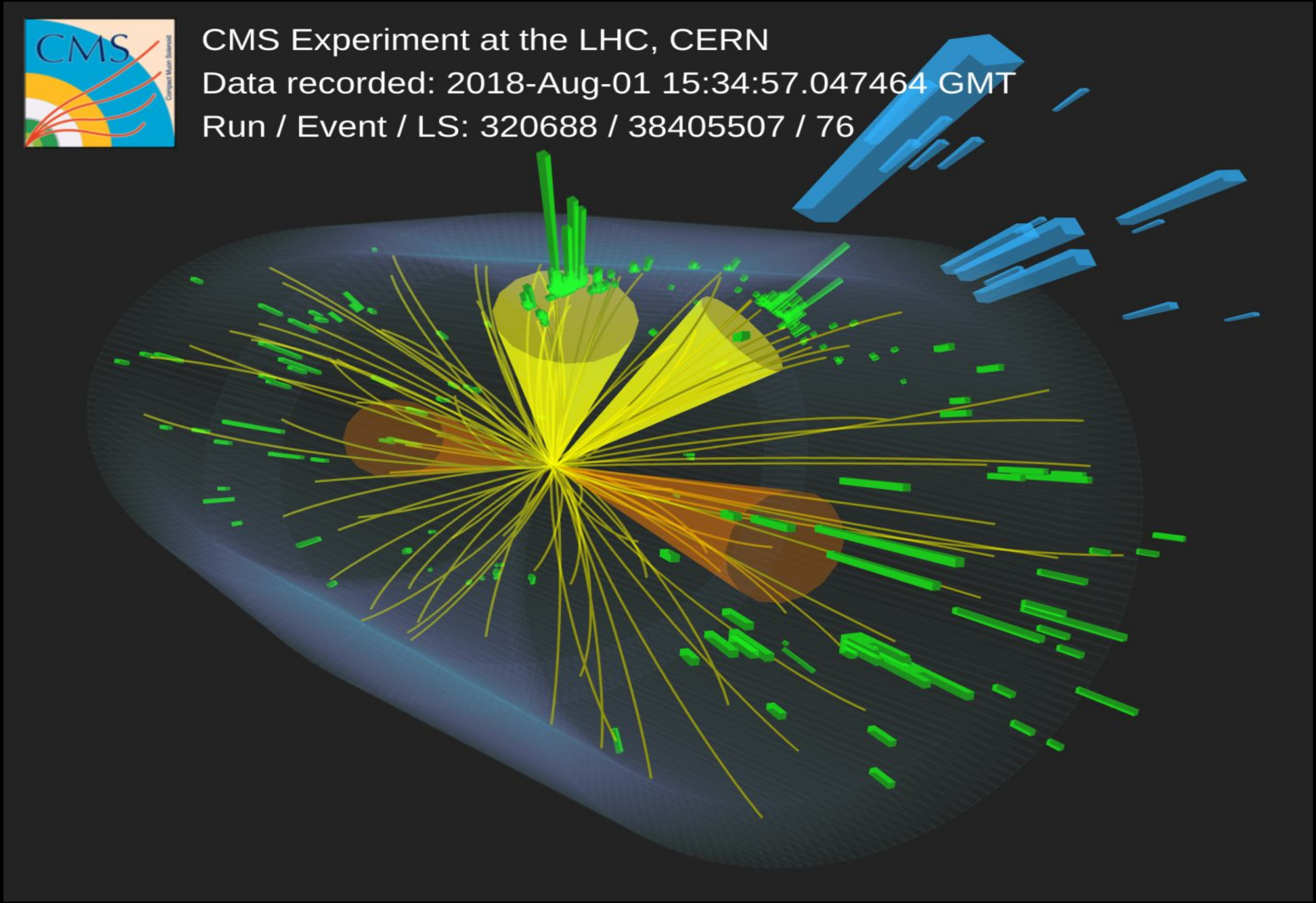
i : number of category, j : order of the polynomial function

→ Order of the polynomial is determined by F-Test

→ Bias study has been performed in each analysis categories by using alternative parametric function to fit data,

→ Insignificant bias has been found (vanishing impact on results)




CMS
CMS Experiment at the LHC, CERN
Data recorded: 2018-Aug-01 15:34:57.047464 GMT
Run / Event / LS: 320688 / 38405507 / 76

VBF H→bb : Results

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signal significance in std. dev.

Inclusive Hbb → VBF + ggF contributions

Process	Observed	Expected
Inclusive Hbb	2.5	2.9
VBFH-bb	2.4	2.7

signal strengths

Process	Observed signal strength
μ_{Hbb}	$0.92^{+0.32}_{-0.32}(\text{stat.})^{+0.31}_{-0.22}(\text{syst.})$
$\mu_{VBF\text{-}Hbb}$	$0.97^{+0.35}_{-0.35}(\text{stat.})^{+0.39}_{-0.28}(\text{syst.})$
μ_{Zbb}	0.94±0.20(stat.)±0.21 (syst.)

→ Measurement of Zbb performed as a standard candle to validate our analysis, Observed VBF Z→ bb

→ Measurements of Hbb, Zbb & VBFH-bb found to be close to the SM prediction [$< 1\sigma$]

Summary

→ VBF Higgs production has been explored in different Higgs decay modes in Run-2 both for inclusive and differential measurements.

→ **VBF H→ bb results from CMS using Run2 data** is very new and presented here.

→ The exclusive VBF H→ bb production is established with a significance of **2.4 σ (exp. = 2.7 σ)**

- the measured signal strength of the VBF H → bb process is $0.97^{+0.53}_{-0.45}$

→ Analysis is almost comparable with ATLAS VBFH → bb results using 126 fb^{-1} data

→ Combination of VBF H→ bb with existing combined Run-2 VBF results would increase the sensitivity further.

→ LHC Run-3 has already been started with centre-of-mass energy of 13.6 TeV, planning to accumulate 300 fb^{-1}

→ Reduction of statistical uncertainties

→ More sophisticated b-tag algorithm, rigorous use of machine learning make the channel more sensitive

please stay tuned for the Run-3 results

Thank you

Additional material

HLT and offline event selection

Level	Requirements	set **A** (36.3 fb^{-1})		set **B** (54.4 fb^{-1})	
		TIGHTVBF	LOOSEVBF	TIGHTVBF	LOOSEVBF
HLT	p_T thresholds	92, 76, 64, 16 GeV		105, 88, 76, 15 GeV	
	number of b-tags	≥ 1	≥ 2	≥ 1	≥ 2
	$\Delta\phi_{bb}$	≤ 1.6	≤ 2.1	≤ 1.9	≤ 2.8
	$\Delta\eta_{jj}$	≥ 4.1	≥ 2.3	≥ 3.5	≥ 1.5
	m_{jj}	≥ 500 GeV	≥ 240 GeV	≥ 460 GeV	≥ 200 GeV
Offline	p_T thresholds	95, 80, 65, 30 GeV		110, 90, 80, 30 GeV	
	jet $\|\eta\| < 4.7$	✓	✓	✓	✓
	Lepton veto	✓	✓	✓	✓
	number of b-tags ≥ 2	✓	✓	✓	✓
	b-jet $\|\eta\| < 2.4$	✓	✓	✓	✓
	$\Delta\phi_{bb}$	≤ 1.6	≤ 2.1	≤ 1.6	≤ 2.1
	$\Delta\eta_{jj}$	≥ 4.2	≥ 2.5	≥ 3.8	≥ 2.5
	m_{jj}	≥ 500 GeV	≥ 250 GeV	≥ 500 GeV	≥ 250 GeV

Reduce the tt and DY contributions

Systematic uncertainties