



中国科学院高能物理研究所
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VBF $H \rightarrow b\bar{b}$ + photon

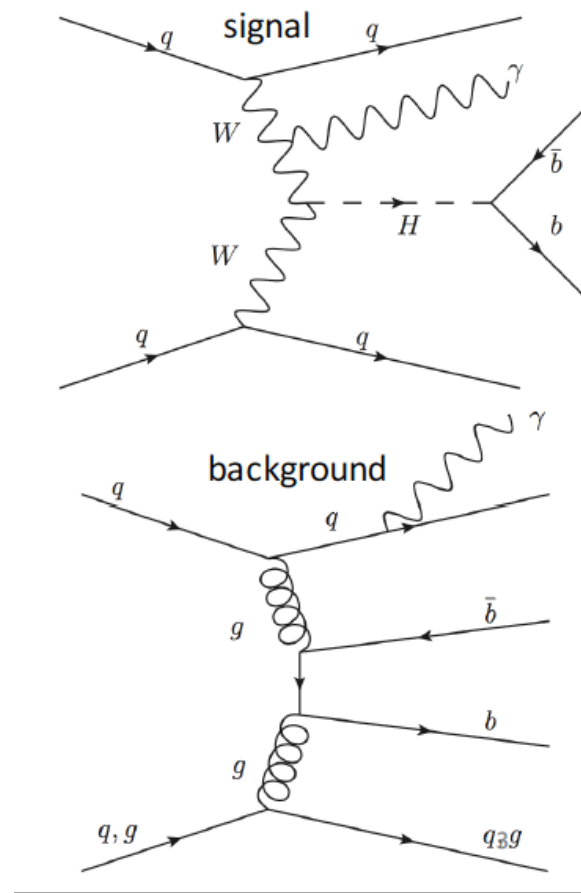
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(IHEP, Chinese Academy of Science)

On behalf of ATLAS collaboration

Introduction

- Search for $H \rightarrow b\bar{b}$ in VBF events containing a central photon
- Advantages of requiring a photon
 - extra handle for trigger
 - suppresses QCD background containing initial state gluons
 - Special VBF production
 - Sensitive to WWH VBF production
 - not sensitive to ZZH VBF
- Existing results for inclusive VBF ($H \rightarrow b\bar{b}$)
 - ATLAS in Run 1
 - observed (expected) upper limit : 4.4 (5.4) x SM
 - CMS in Run 1
 - observed (expected) significance : 2.2 (0.8)
 - observed (expected) upper limit : 5.5 (2.5) x SM
 - CMS in Run 2 (2015 data)
 - observed (expected) upper limit: 3.0 (5.0) x SM
 - **None for VBF + photon**



Major Background process

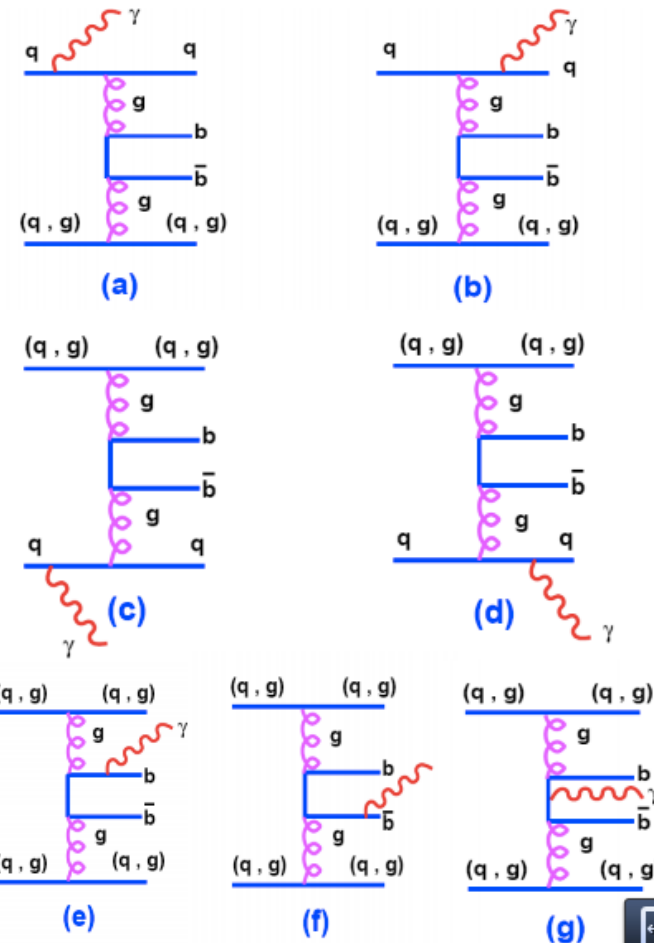
- QCD pbbjj + γ production

Inspired by Barbara Mele's paper
<http://arxiv.org/abs/hep-ph/0702119>

**bckg is less active by
 requiring a central photon**

**dynamical effect:
 destructive interference
 for gamma at large angles
 a) + b) and c) + d)**

**dominant effect, but
 suppressed by the b-quark
 electric charge**



MC Samples

- Signal samples (VBF $H \rightarrow b\bar{b} + \gamma$):
 - generated with Madgraph, parton shower by Pythia8
- $Z(b\bar{b})\gamma + \text{jets}$ (resonance background)
 - EWK VBF $H \rightarrow b\bar{b} + \gamma$
 - generated with Madgraph, parton shower by Pythia8
 - QCD VBF $H \rightarrow b\bar{b} + \gamma$
 - generated with Madgraph, parton shower by Pythia8
- QCD $\gamma b\bar{b} + \text{jets}$ (Non resonance background)
 - generated with Madgraph, parton shower by Pythia8
 - For MVA training

Trigger

- Threshold for single photon trigger and 4jets triggers are high.
 - Single photon: trigger EF_g120_loose (ET>120GeV. too high)
 - General 4jet triggers : ET>100GeV (too high)
- Dedicated trigger developed in 2015 for this analysis.
- Analysis is mainly based on VBF0b trigger.
 - L1 item : L1EM22VHI (trigger on EM object with ET>22GeV)
 - HLT :
 - Medium ID photon, pT >25GeV
 - 4 HLT jets pT >35GeV, |eta|<4.9
 - Mjj>700GeV

Nick name	Trigger name	Integrated lumiosity
VBF0b	HLT_g25_medium_L1EM22VHI_4j35_0eta490_invm700	2.5 fb-1 (2015) 10.1 fb-1 (2016)

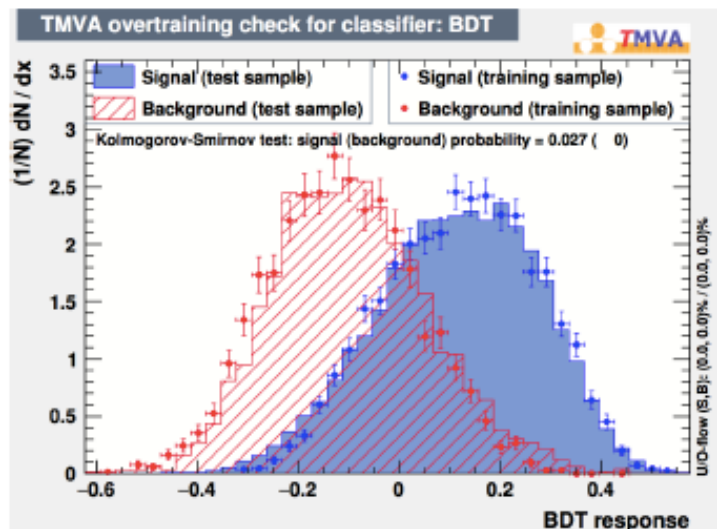
Event pre-selection

Selection	Requirement
Derivation	HIGG5D3
Trigger	HLT_g25_medium_L1EM22VHI_4j35_0eta490_invm700
Event quality (data only)	pass GRL no Tile, LAr, SCT and Core error
Primary Vertex	At least one primary vertex
Photon	≥ 1 photon
Jets	≥ 4 jets ($p_T > 40$ GeV, $ \eta < 4.5$) ≥ 2 jets in $ \eta < 2.5$ (central jets)
Higgs signal jet (BB)	two central jets with highest MV2c10 weights
VBF jets (JJ)	pair of non-signal jets with highest invariant mass
b -jets	2 b -tagged jets (tagged on the BB pair with MV2c10 at 77% fixed cut working point)
m_{JJ}	$m_{JJ} > 800$ GeV
$p_T(BB)$	$p_T(BB) > 80$ GeV

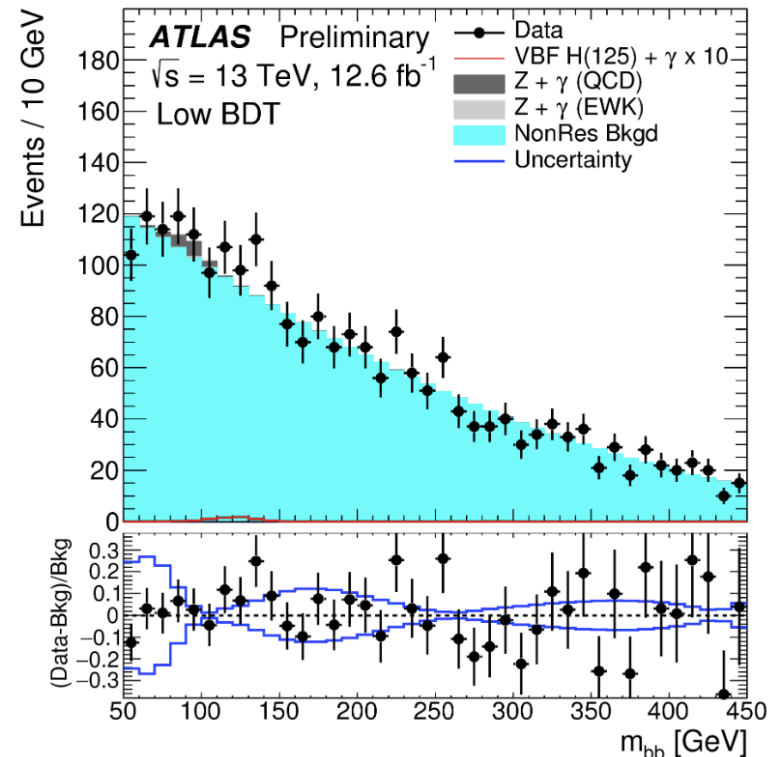
Analysis strategy

- Pre-selection cut
- MVA analysis (boosted decision tree)
 - category the events into three category
 - VBF like events in high BDT output category
 - The correlation between MVA input variable and m_{bb} is weak
- Extract signal from m_{bb} fit

use a BDT to separate the signal and non-resonant background



Perform fit in m_{bb} spectrum



MVA studies

- BDT training samples:
 - signal: HbbjjaSM125 (direct tag)
 - background: NonResbbjja (truth tag)
- 11 BDT input variables:

$$p_T^{balance} = \frac{(p^{b_1} + p^{b_2} + p^{j_1} + p^{j_2} + p^\gamma)_T}{p_T^{b_1} + p_T^{b_2} + p_T^{j_1} + p_T^{j_2} + p^\gamma}$$

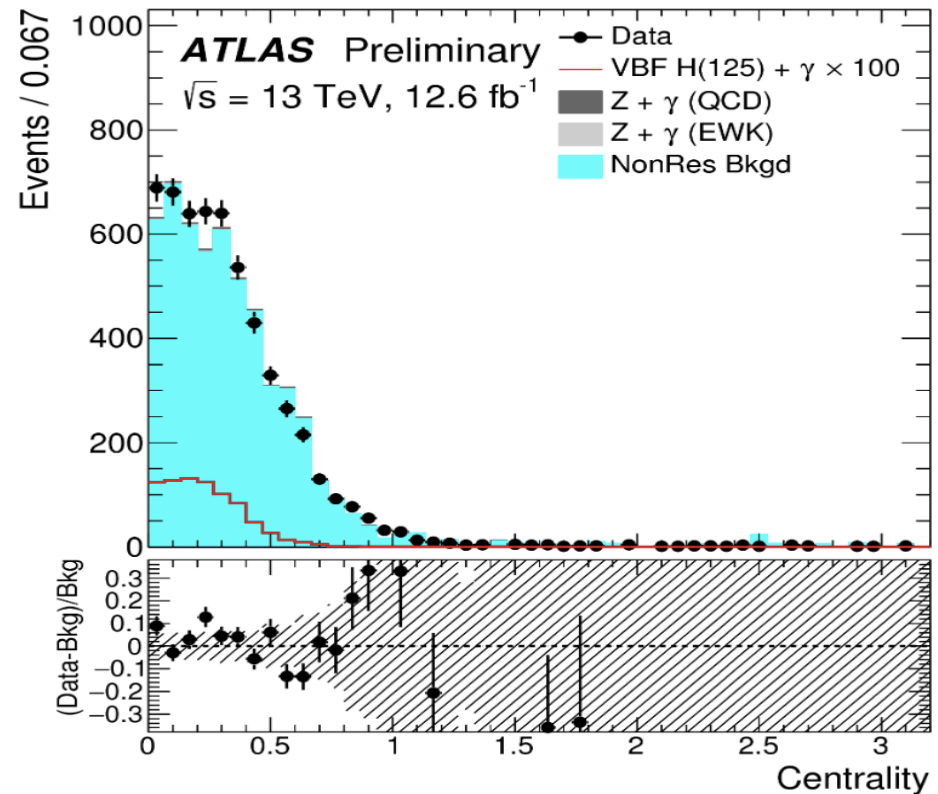
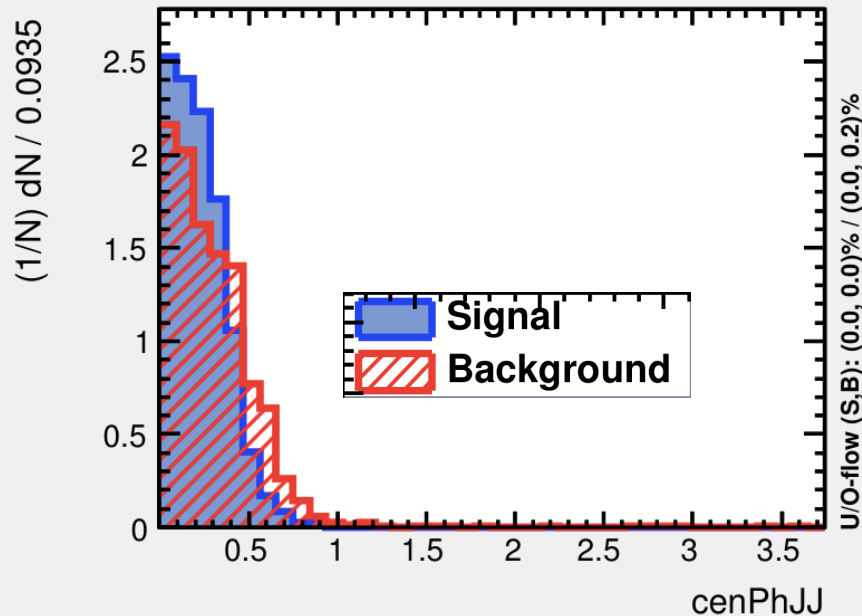
$$centrality(\gamma) = \left| \frac{y_\gamma - \frac{y_{j_1} + y_{j_2}}{2}}{y_{j_1} - y_{j_2}} \right|$$

variable	definition
dRB1Ph, dRB2Ph, dRJ1Ph, dRJ2Ph	angular separation between the selected jets and the photon
mJJ, dEtaJJ	kinematics of the VBF jets
WidthJ1, WidthJ2	calorimeter jet width of the VBF jets
pTBal	pT balancing variable for selected final state objects
cenPhJJ	centrality of the photon with respect to the VBF jets
HT_soft	scalar sum pT of the soft TrkJets (pT>7GeV, not close to the final state objects)

MVA Input variable: centrality and Mjj

$$centrality(\gamma) = \left| \frac{y_\gamma - \frac{y_{j_1} + y_{j_2}}{2}}{y_{j_1} - y_{j_2}} \right|$$

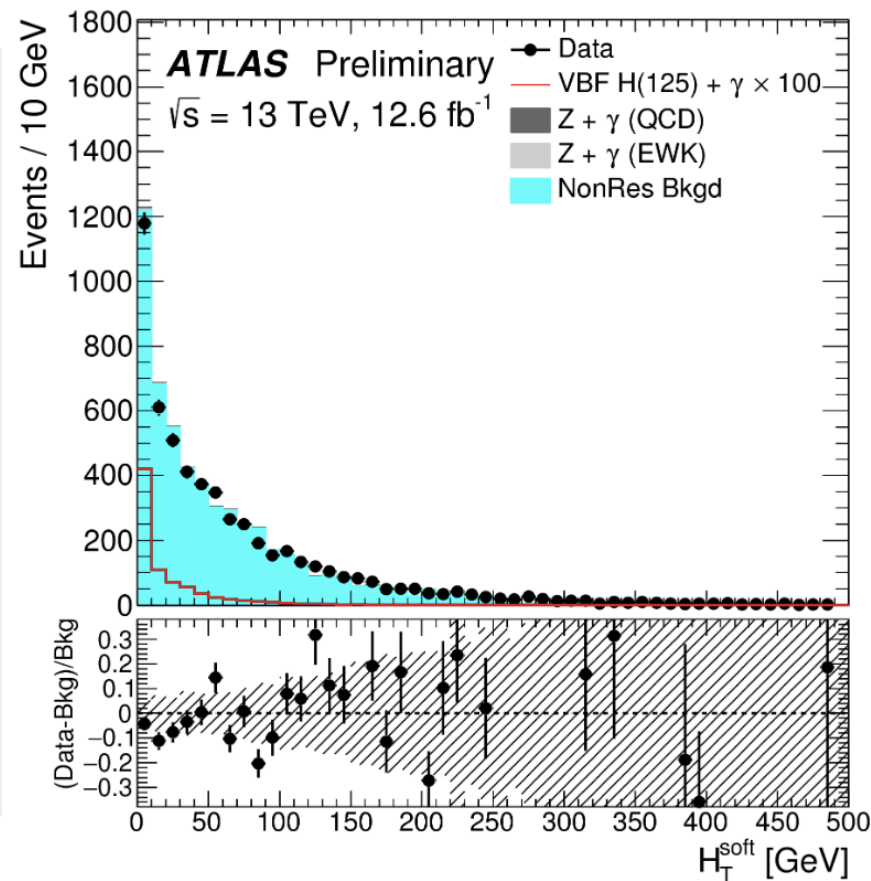
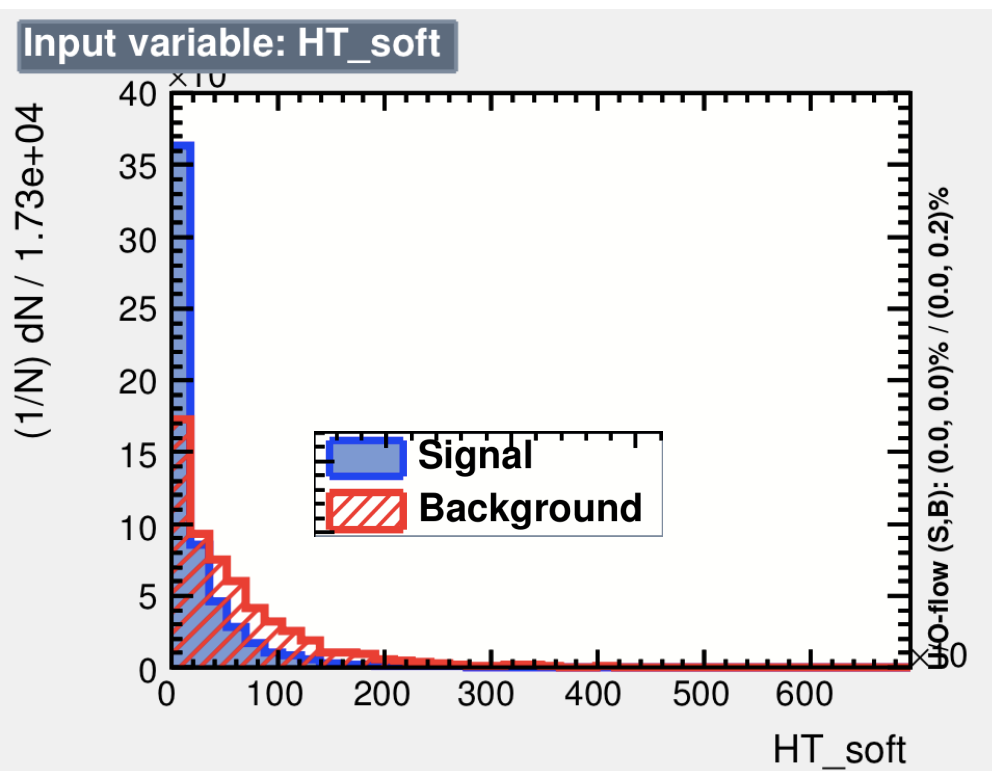
Input variable: cenPhJJ



MVA Input variable: H_T^{soft}

- Low QCD activity in rapidity gap of two VBF jets for VBF signature

H_T^{soft} : the scalar sum p_T of the soft TrackJets with $p_T > 7$ GeV (HT_{soft}).



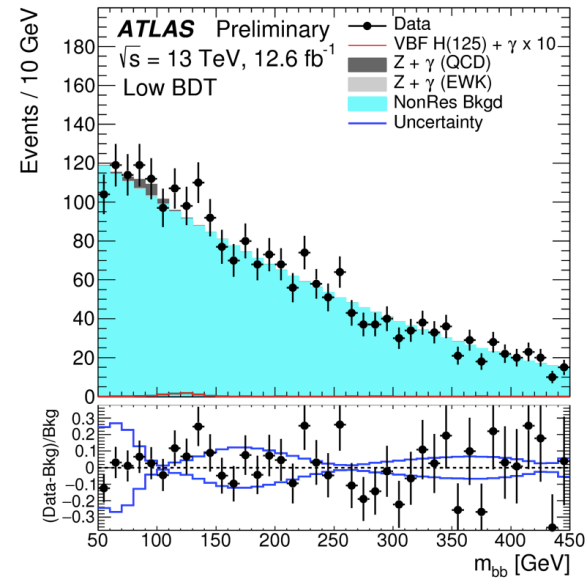
m_{bb} Fit configurations

- H+ γ fit configuration
 - H+ γ normalization μ_H is the parameter of interest.
 - H+ γ and Z+ γ shape from MC simulation
 - Z+ γ normalization from MC predictions
 - The normalization of are from MC simulation.
 - Non-resonance background is fitted as 2nd order polynomial
- Z+ γ fit configuration
 - EWK Z(bb) γ +jets and QCD Z(bb) γ +jets are considered as signal
 - H+ γ and Z+ γ shape from MC simulation
 - H+ γ is normalization from MC simulation
 - Non-resonance background is fitted as 2nd order polynomial

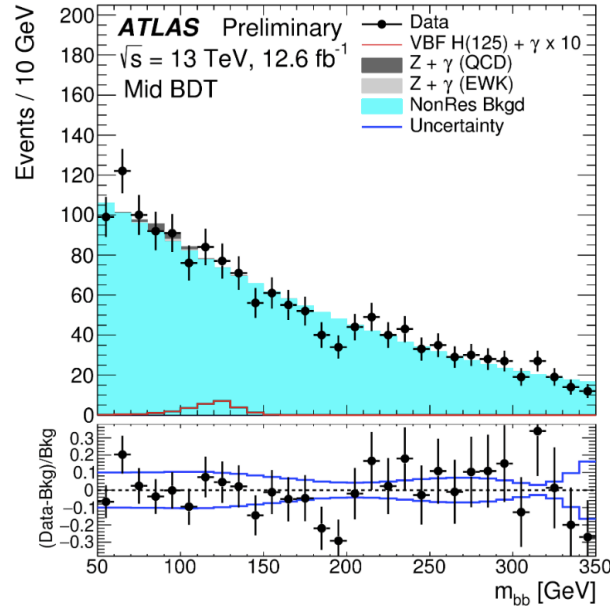
$$\mathcal{L}(\mu, \theta) = \prod_{j=1}^N \frac{(\mu s_j(\theta) + b_j(\theta))^{n_j}}{n_j!} e^{-(\mu s_j(\theta) + b_j(\theta))} \prod_{i=1}^Q f_X(\theta_i | \bar{\theta}_i, \sigma_{\theta_i}) \prod_{l=1}^P \mathcal{G}_X(\theta_l | \bar{\theta}_l, \sigma_{\theta_l})$$

Mbb fit with 3 category : high/medium/low BDT region

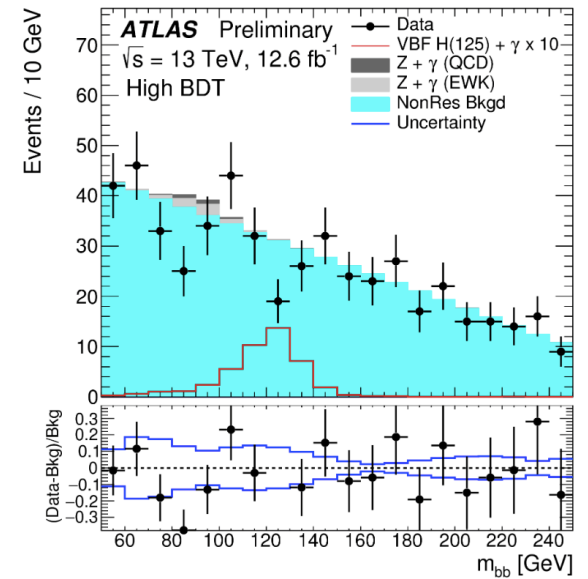
Low BDT



Medium BDT



High BDT



BDT categories	BDT score	mBB fit range
low	BDT < -0.1	[50, 450] GeV
medium	-0.1 < BDT < 0.1	[50, 350] GeV
high	BDT > 0.1	[50, 250] GeV

Result

ATLAS-CONF-2016-063

- H+ γ fit configuration
 - H+ γ normalization μ_H is the parameter of interest.
 - Z+ γ normalization and Z+ γ shape from MC simulation
- Z+ γ fit configuration
 - EWK Z(bb) γ +jets and QCD Z(bb) γ +jets are considered as signal
 - H+ γ normalization and H+ γ shape from MC simulation

Result	$H(\rightarrow b\bar{b}) + \gamma jj$	$Z(\rightarrow b\bar{b}) + \gamma jj$
Expected significance	0.4	1.3
Expected p -value	0.4	0.1
Observed p -value	0.9	0.4
Expected limit	6.0 $^{+2.3}_{-1.7}$	1.8 $^{+0.7}_{-0.5}$
Observed limit	4.0	2.0
Observed signal strength μ	-3.9 $^{+2.8}_{-2.7}$	0.3 ± 0.8

Systematic uncertainties

- Theoretical uncertainties for H+gamma and Z+gamma
 - QCD scale systematics
 - Parton shower systematics
 - PDF uncertainty
- Non-resonance background systematics
 - Statistics in mbb sideband region
 - The bias in fit function
- Experimental uncertainties
 - Trigger uncertainty
 - Modelling of MVA input variable (jet width , HTsoft)
 - LUMI uncertainty
 - Jet systematics
 - Jet energy scale
 - Photon systematics
 - EM energy scale and resolution
 - Photon ID efficiency
 - B-tagging efficiency systematics

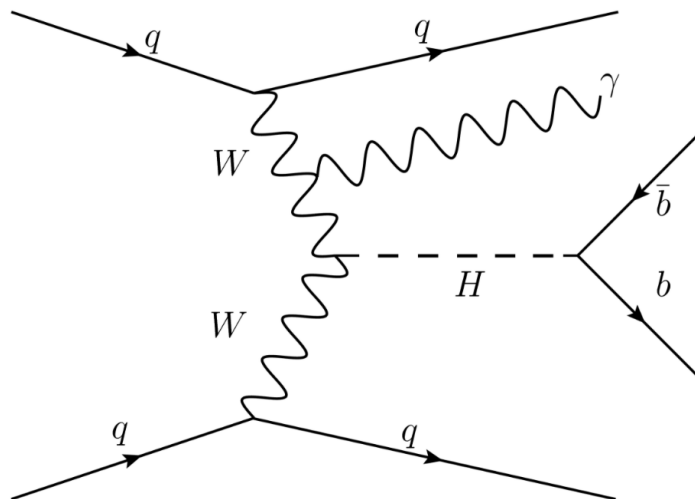
Impact of each systematics

- Non-resonance background systematics is the leading systematics.

Uncertainty source	Uncertainty $\Delta\mu$
Non-resonant background uncertainty in medium-BDT region	0.22
Non-resonant background uncertainty in high-BDT region	0.21
Non-resonant background uncertainty in low-BDT region	0.17
Parton shower uncertainty on $H + \gamma$ acceptance	0.16
QCD scale uncertainty on $H + \gamma$ cross section	0.13
Jet energy uncertainty from calibration across η	0.10
Jet energy uncertainty from flavour composition in calibration	0.09
Integrated luminosity uncertainty	0.08

Summary

- First VBF $H(->bb)+\gamma$ search in LHC.
- The observed 95% CL upper limit on signal cross section
 - 4 times SM cross section expectation.
- A validation measurement with $Z(->bb)+\gamma$
 - signal strength: 0.3 ± 0.8
 - Observed upper limit is 2 times SM cross section expectation.



Introduction

Inspired by Barbara Mele's paper
<http://arxiv.org/abs/hep-ph/0702119>

- Introduce a new channel in VBF $H \rightarrow b\bar{b}$
- $pp \rightarrow h(bb) jj + \gamma$
 - Measurement of $b\bar{b}H$ and WWH coupling
 - By requiring a central photon
 - S/B ratio is much better than VBF $H \rightarrow b\bar{b}$
 - Help to do trigger the events

