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Search for $H \rightarrow b\bar{b}$ decays in VBF+gamma final state with the ATLAS detector

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on behalf of the ATLAS Collaboration

Institute of High Energy Physics ,
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The 4th CLHCP workshop at Central China Normal University, Wuhan

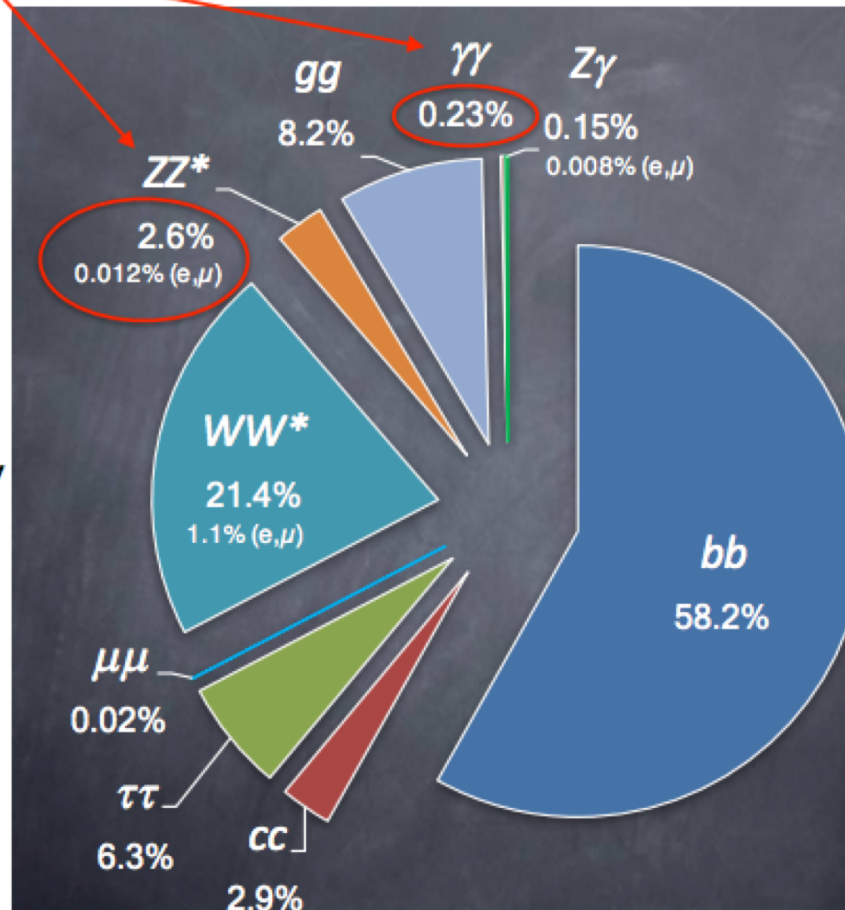
Introduction

- $H \rightarrow b\bar{b}$ is the Dominant Decay mode of Higgs Boson(58%)
- Motivation: Search $H \rightarrow b\bar{b}$ decay mode in VBF final state

$ZZ, \gamma\gamma$: high mass resolution channels
mass and precise differential measurements

WW : High BR, but low mass resolution

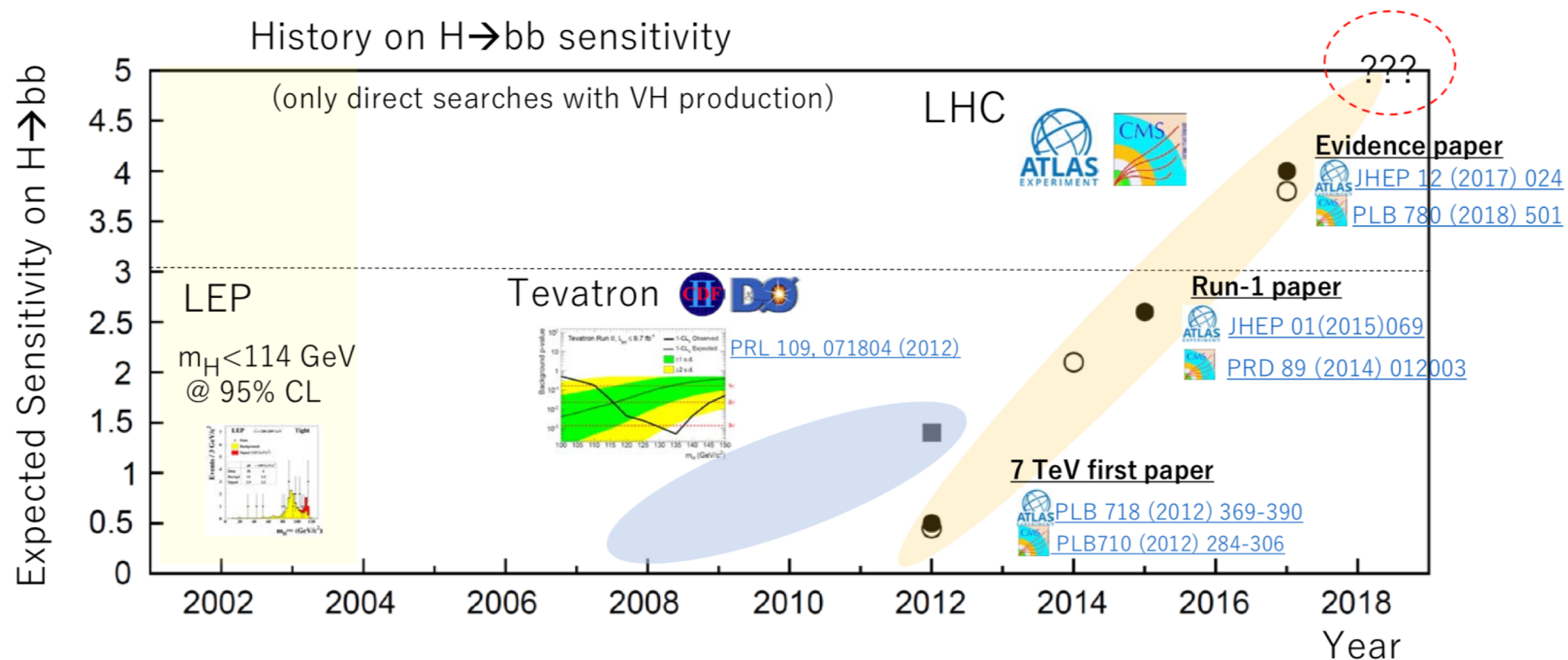
$\mu\mu$: very small BR, but access to coupling to 2nd generation fermions



$bb, \tau\tau$: high BR, but low S/B, important to directly probe Higgs boson coupling to fermions

Road to discovery of $H \rightarrow b\bar{b}$

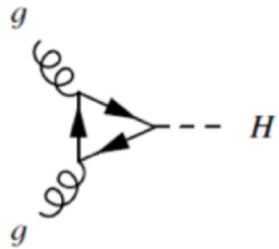
- Started in LEP era, developed in Tevatron, found at LHC



H- $\rightarrow$ bb searches in different channels

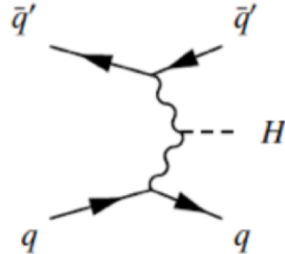
- H- $\rightarrow$ bb is hadronic final state
 - This talk focus on ggF+VBF channel.
 - Next talk by Yanhui about VH and H- $\rightarrow$ bb combination.

ggF: $\sigma = 43.9$ pb



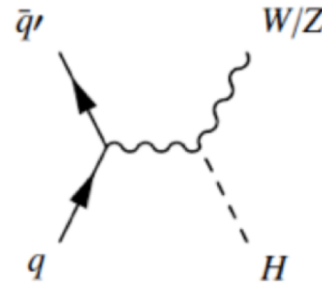
Largest production
Tough to use due to
huge multi-jet
background
(CMS uses boosted
channel.)

VBF: $\sigma = 3.7$ pb



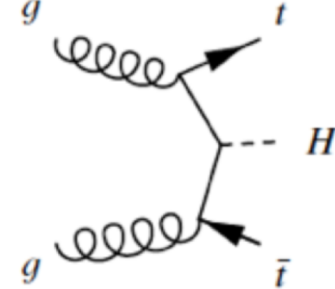
Signature of Forward jets
 $\rightarrow$ can be triggered.
Photon associated VBF
signature enhances
sensitivity!
 $\rightarrow$ see next page.

VH: $\sigma = 2.3$ pb



High p_T lepton from W or
Z boson.
 $\rightarrow$ Trigger & suppress
multi-jet background.
Main channel for H $\rightarrow$ bb!

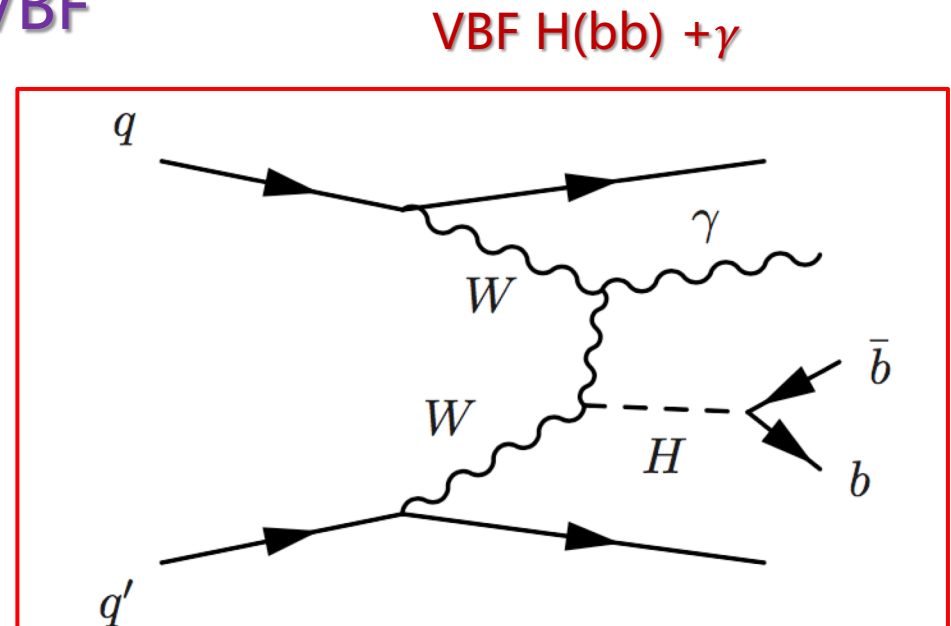
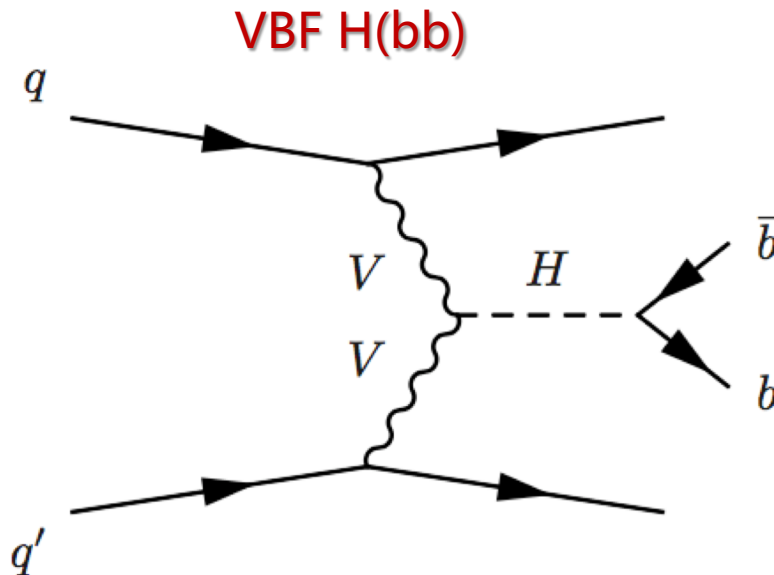
ttH: $\sigma = 0.50$ pb



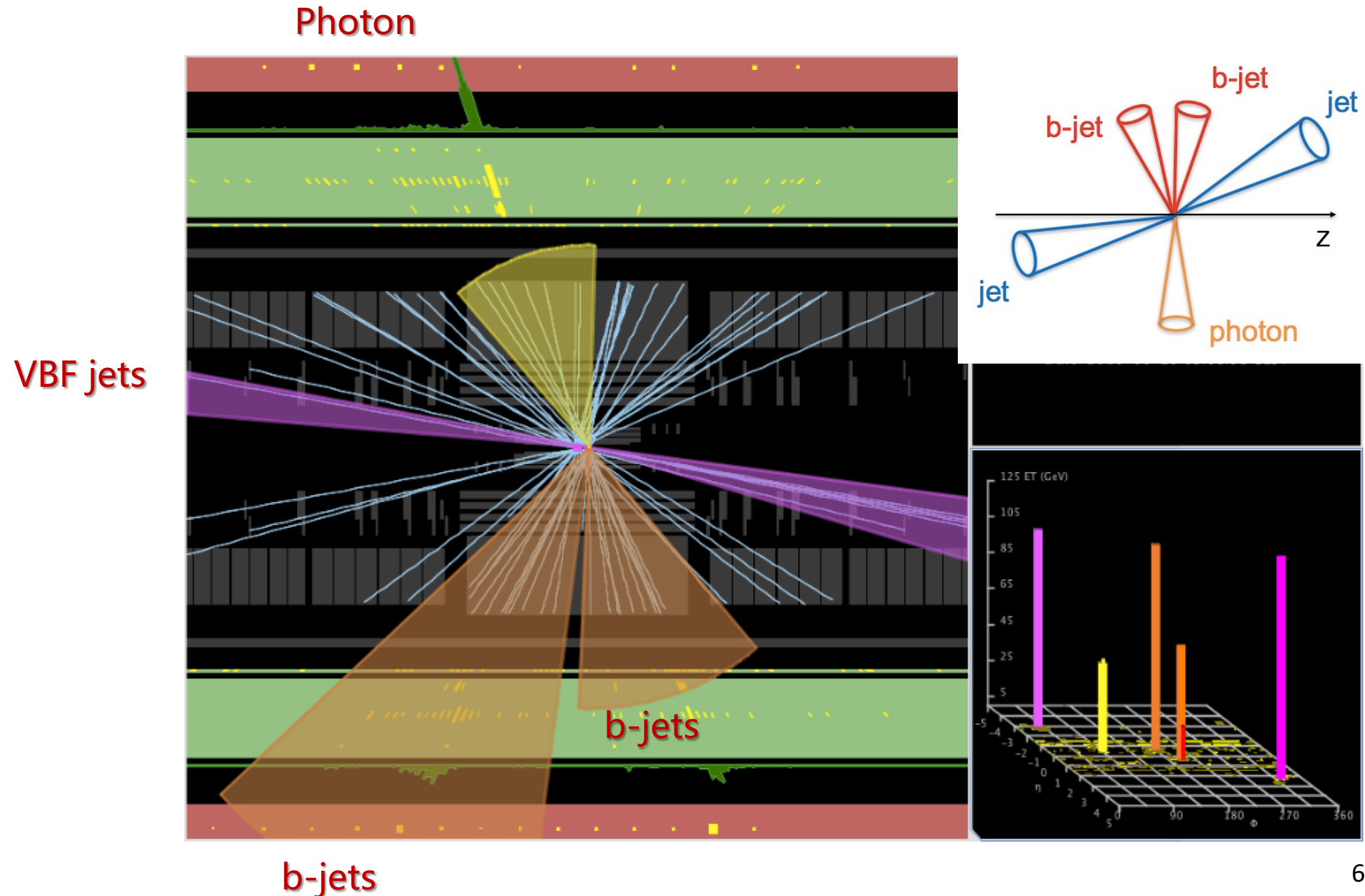
Signature of ttbar pair
 $\rightarrow$ can be triggered.
- all hadronic
- lepton(s) w/ H $\rightarrow$ bb
- multi-leptons
- H $\rightarrow$ $\gamma\gamma$

VBF H(bb) analysis

- IHEP team propose 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
 - Sensitive to WWH VBF production
 - not sensitive to ZZH VBF



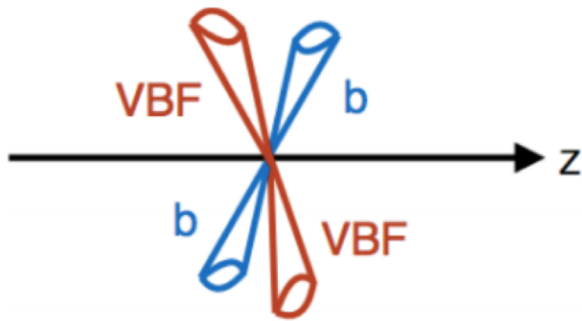
Event display for VBF $H(bb)+\gamma$



Trigger

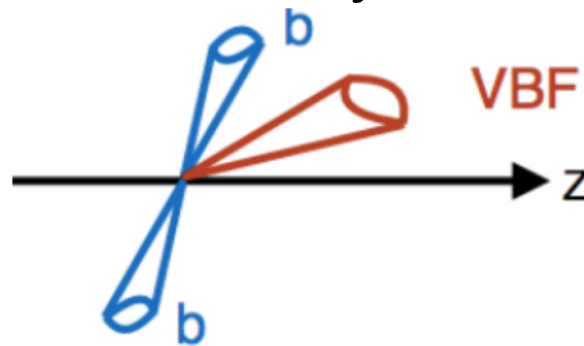
- divided into 3 channels based on triggers:
 - VBF inclusive
 - **Two central** : 4 central jets with 2 bjet($2b+2j$)
 - **Four central**: 2 central + 1 forward trigger jet ($1fj+2b$)
 - VBF+photon
 - **Photon**: photon + 2bjets+2 forward jets ($\gamma+2b+2fj$)

L1 trigger: 4 central Jet



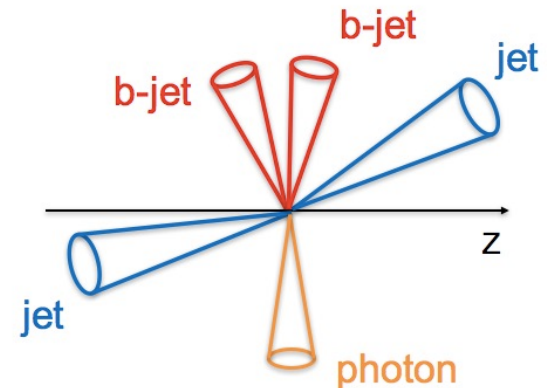
Four central
Channel ($2b+2j$)

L1: 1 forward jet
+2 central jets



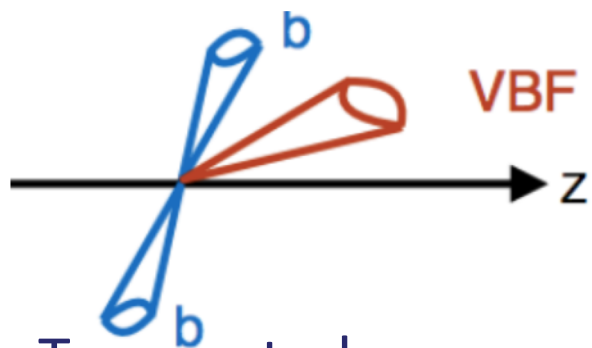
Two central
Channel ($1fj+2b$)

L1: 1 EM object

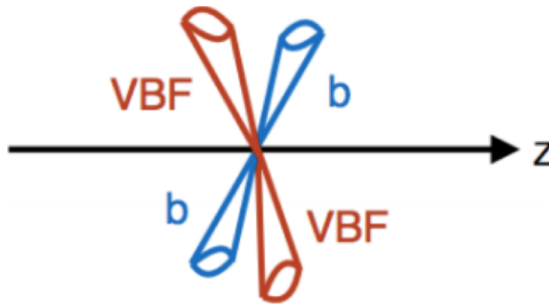


Photon channel
 $\gamma+2b+2fj$

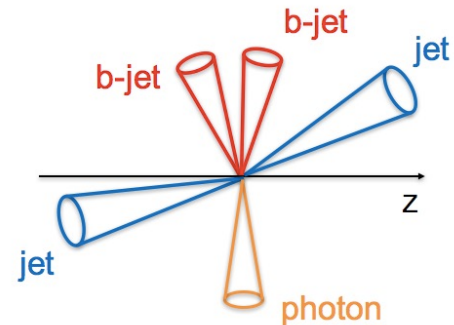
Event Selection



Two central
Channel (1fj+2b)



Four central
Channel (2b+2j)



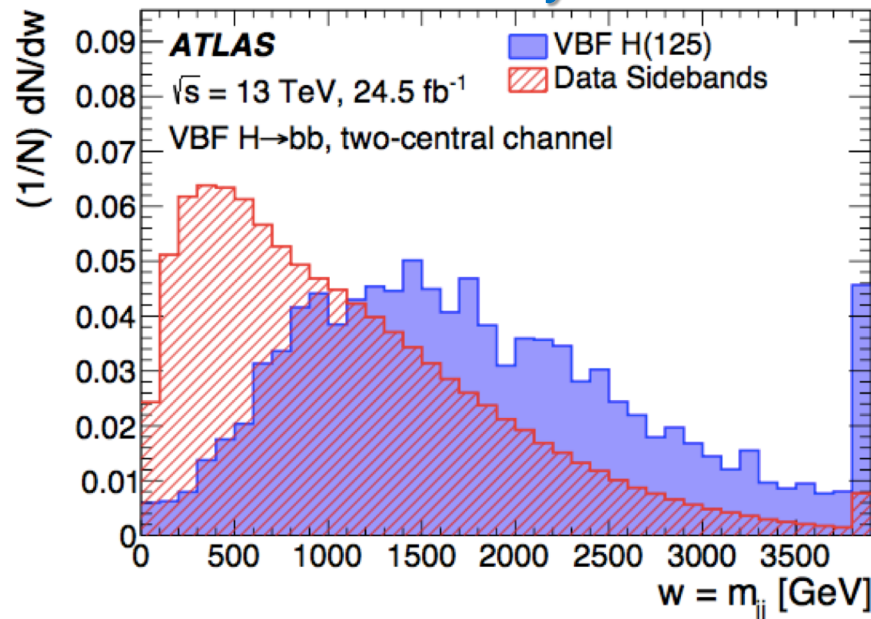
Photon channel
 $\gamma+2b+2fj$

	Two central	Four central	Photon
2 b-jet	$p_T > 95\text{GeV}$ $p_T > 70\text{GeV}$	$p_T > 55\text{GeV}$	$p_T > 40\text{GeV}$
2 VBF jets	$p_T > 60\text{GeV}, 3.2 < \eta < 4.4$ $p_T > 20\text{GeV}, \eta < 4.4$	$p_T > 55\text{ GeV}, \eta < 4.4$ Veto event with jet $p_T > 60\text{GeV}, 3.2 < \eta < 4.4$	$p_T > 40\text{GeV}$ $ \eta < 4.4$
Photon			$E_T > 30\text{GeV}$
Event topology	$p_T(bb) > 160\text{GeV}$	$p_T(bb) > 150\text{GeV}$	$p_T(bb) > 80\text{GeV}$ $M(jj) > 800\text{GeV}$

Inclusive analysis veto data events in photon channel
orthogonality between different channels

Boosted Decision Tree (BDT) Analysis

- 11 variables used in BDT analysis

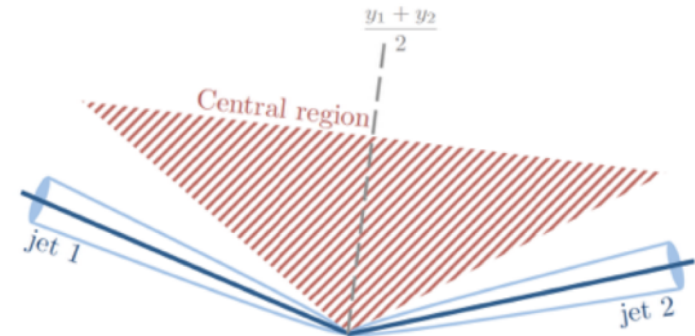


	VBF H(bb) Inclusive	VBF H(bb)+Photon
g/q separation	Ntrk(j1),Ntrk(j2) min $\Delta R(J1)$,min $\Delta R(J2)$	Ntrk(j1),Ntrk(j2)
VBF jets	$p_T(JJ)$, M(JJ), $\Delta M(JJ)$ Max($\eta(J1)$, $\eta(J2)$)	$p_T(JJ)$, M(JJ), $\Delta\eta(JJ)$
Color connection	p_{balance} η^* (Higgs centrality)	p_{balance} Photon Centrality
Angular	$\cos \theta(bb,jj)$	$\Delta R(b1,\gamma)$, $\Delta R(b2,\gamma)$, $\Delta\phi(bb,jj)$, $\cos \theta$

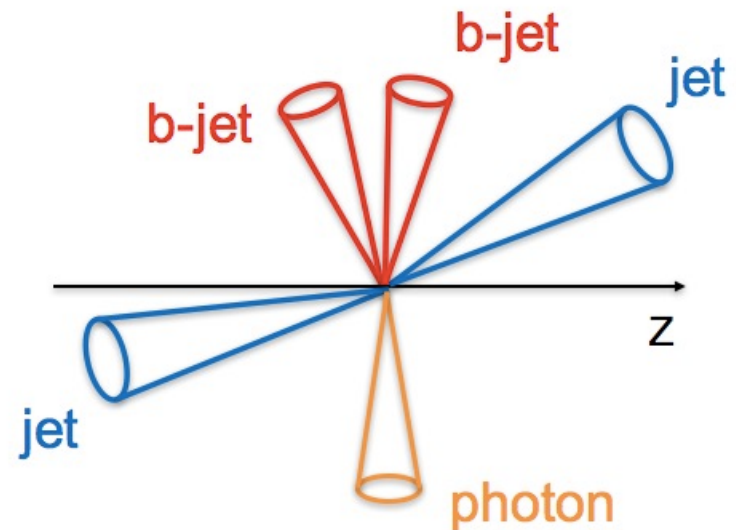
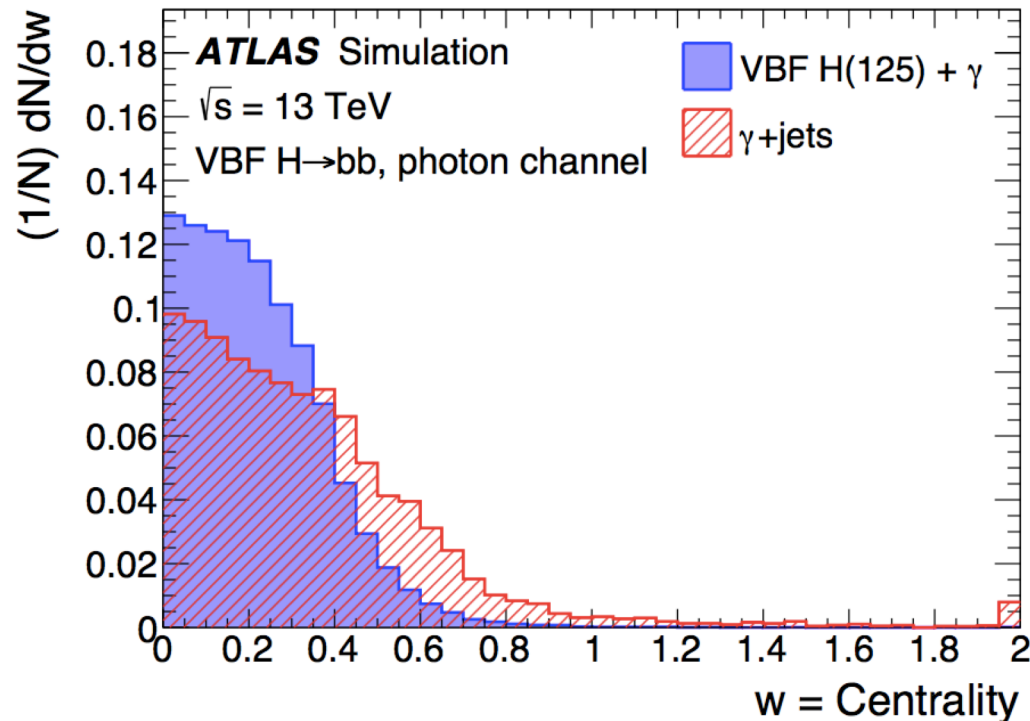
MVA Input variable: photon centrality

Use 11 variables used in BDT analysis

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

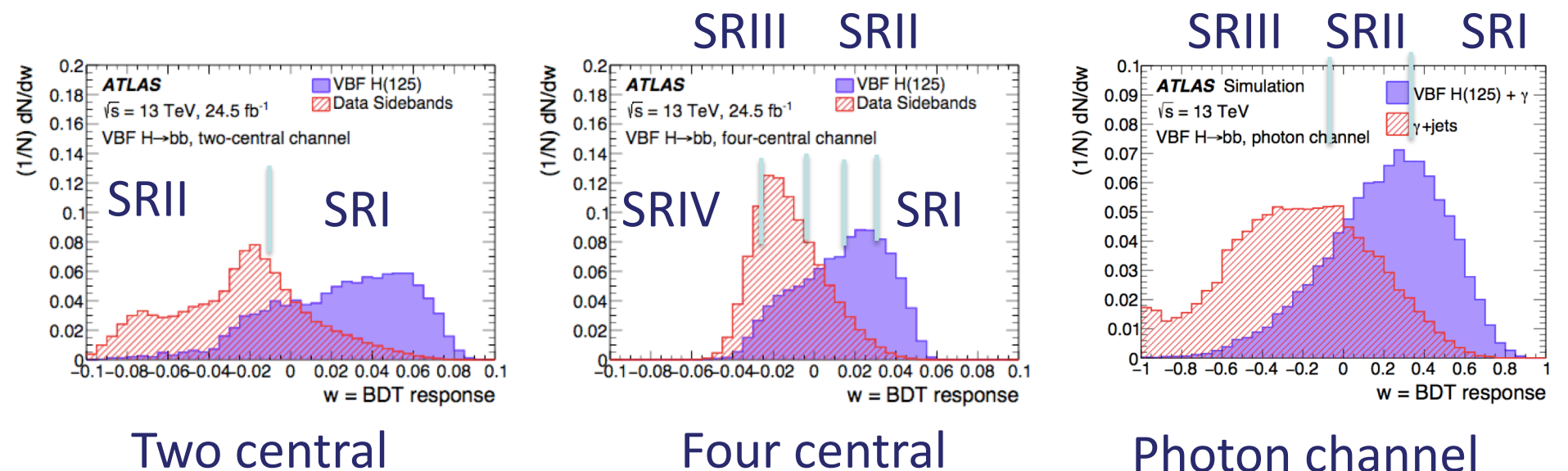


No color connection between VBF jets and b jets in signal



BDT response

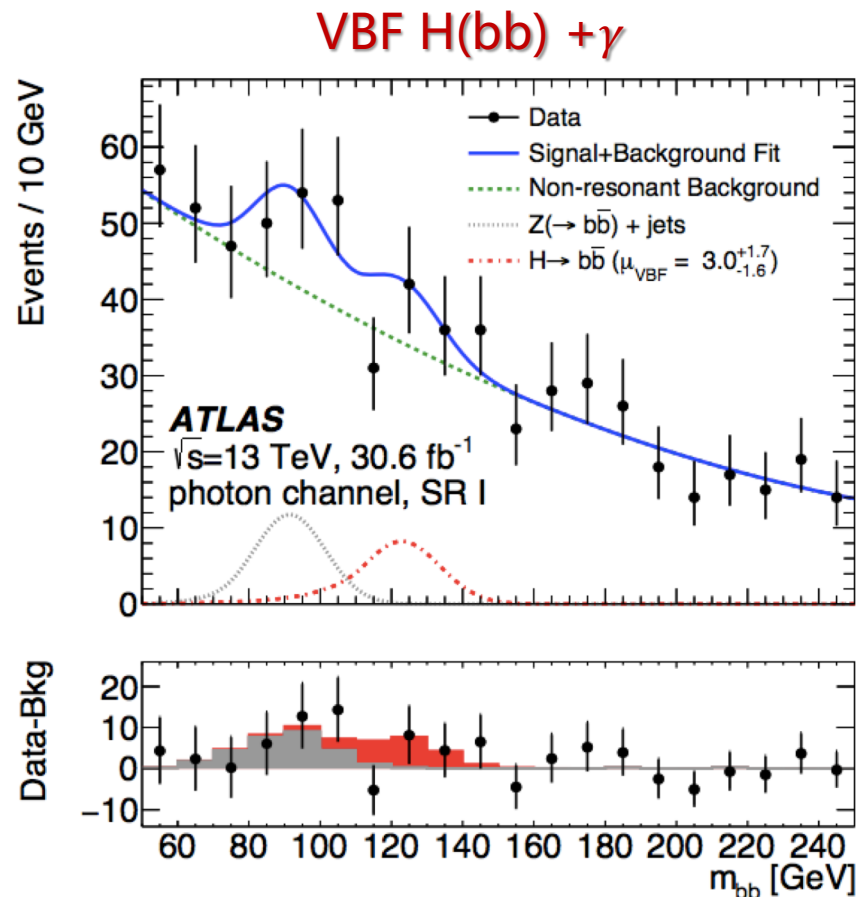
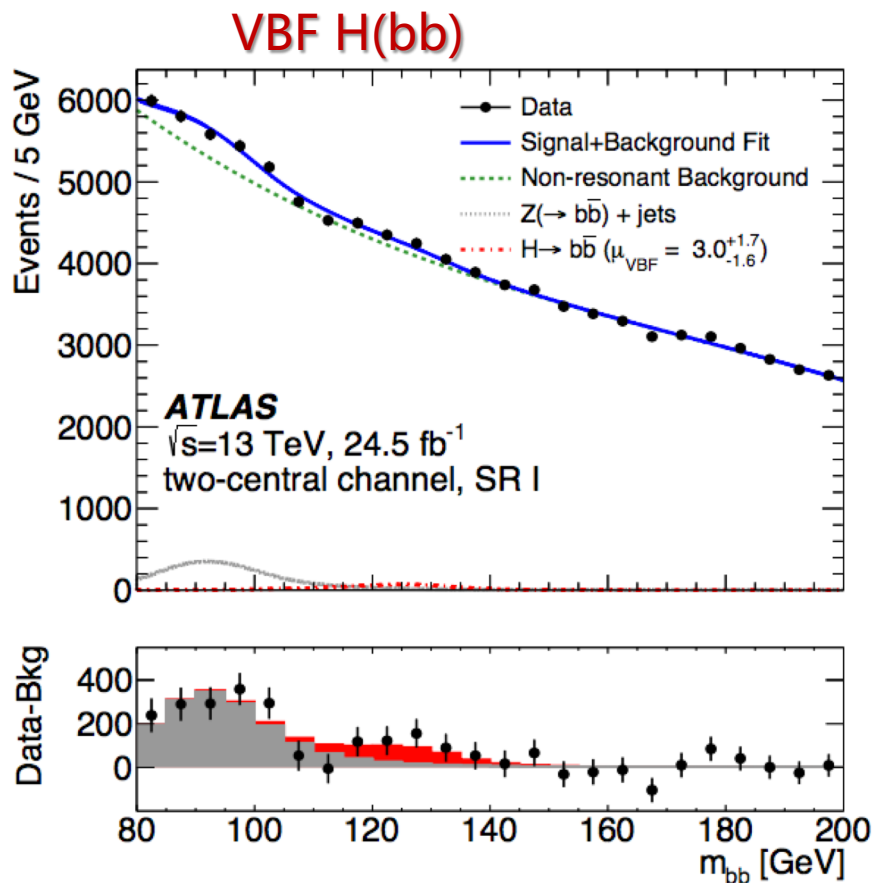
- Divide into 9 categories based on BDT weight
 - Expected Higgs and Z events in $100\text{GeV} < m(bb) < 140\text{GeV}$



Channel	Two-central		Four-central				Photon		
Region	SR I	SR II	SR I	SR II	SR III	SR IV	SR I	SR II	SR III
Higgs boson	340^{+120}_{-130}	165^{+50}_{-29}	167^{+60}_{-58}	101^{+40}_{-21}	183^{+50}_{-46}	304^{+100}_{-51}	$21.1^{+7.7}_{-7.1}$	$20.1^{+9.5}_{-7.2}$	$10.6^{+7.8}_{-4.1}$
Z+jets ($Z\gamma$)	470^{+140}_{-180}	230^{+210}_{-230}	22^{+80}_{-22}	197^{+90}_{-95}	720^{+190}_{-180}	$1\ 260^{+270}_{-250}$	$5.8^{+3.3}_{-3.6}$	$1.1^{+5.8}_{-1.1}$	$9.8^{+7.8}_{-7.9}$
Non-resonant bkg	$34\ 620^{+310}_{-280}$	$95\ 620^{+420}_{-420}$	$12\ 870^{+150}_{-190}$	$19\ 340^{+200}_{-240}$	$59\ 340^{+340}_{-340}$	$146\ 930^{+630}_{-510}$	$140.4^{+6.1}_{-6.8}$	518^{+10}_{-13}	$1\ 296^{+18}_{-19}$
Data	35 496	95 802	13 139	19 611	60 314	148 413	162	565	1 270

VBF H(bb) background fit

- Simultaneous $m(bb)$ Fit to all 9 regions Phys. Rev. D 98 (2018) 052003
 - Signal shape is modelled by crystal ball function
 - Background shape is modelled by polynomial function



VBF H(bb) result and major issue

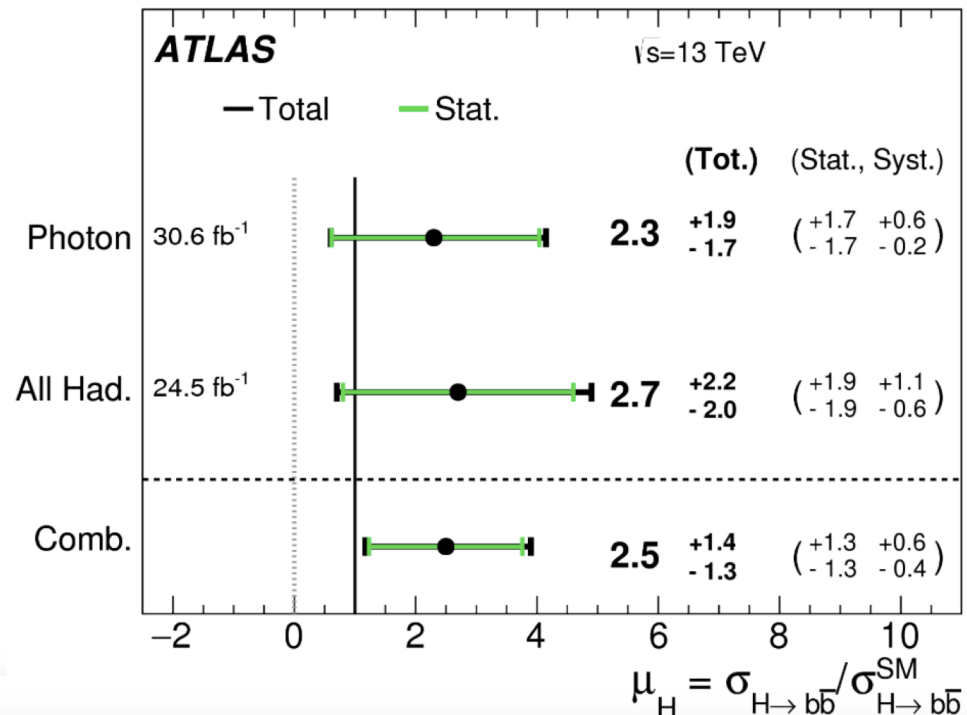
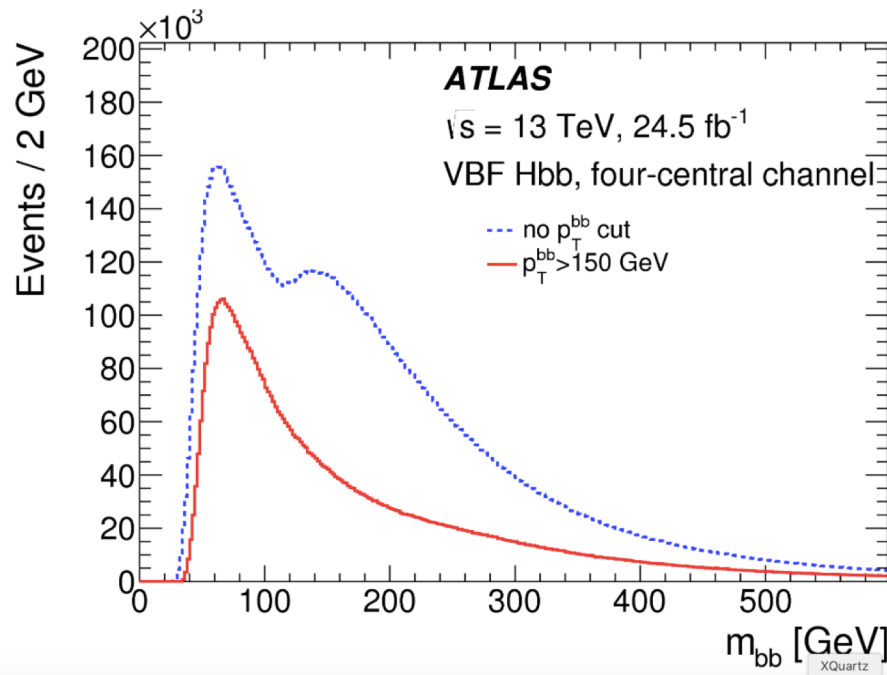
- 1.9 σ (0.7 σ) Obs(Exp) significance using VBF H(bb)

- Statistics uncertainty dominated

Phys. Rev. D 98 (2018) 052003

- Inclusive VBF H(bb) is limited by

- Jet Trigger p_T threshold too high
- Need very high $p_T(bb)$ cut to reduce trigger bias
- Z+jets modelling unc. in high $p_T(bb)$ is large

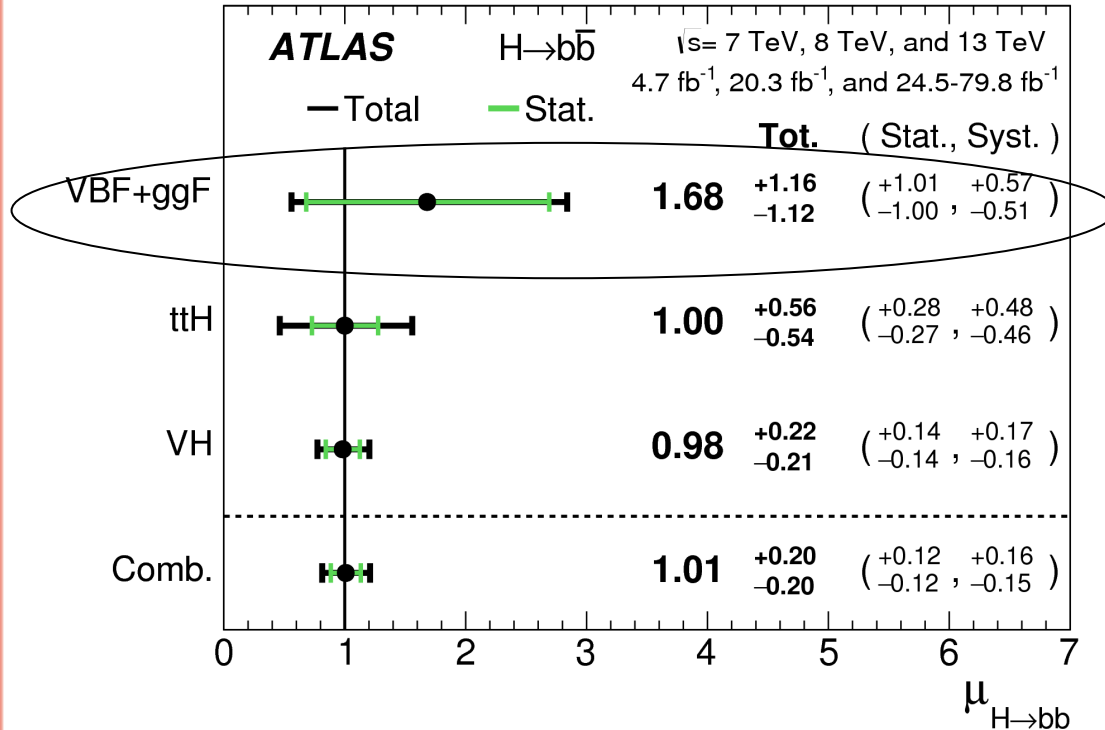


Summary

- ATLAS presented $H \rightarrow b\bar{b}$ observation in ICHEP2018 (5.4σ)
 - VBF+ggF channel contributed 1.9σ (0.7) Obs(Exp) significance

$H \rightarrow b\bar{b}$ combination

See more details
In the talk by Yanhui



Significance:
5.4 σ observed
(5.5 σ expected)

Observation of
 $H \rightarrow b\bar{b}$!!

Systematics in VBF H(bb) search

Phys. Rev. D 98 (2018) 052003

