中国科学院高能物理研究所

Institute of High Energy Physics Chinese Academy of Sciences

Observation of H->bb

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2018年第十三届TeV物理工作组学术研讨会

Outline

- Search for SM H→bb (Dominant Decay Channel)
  - VBF H→bb analysis
  - VH(→bb)
  - ttH(bb)
- BSM search with H->bb final state

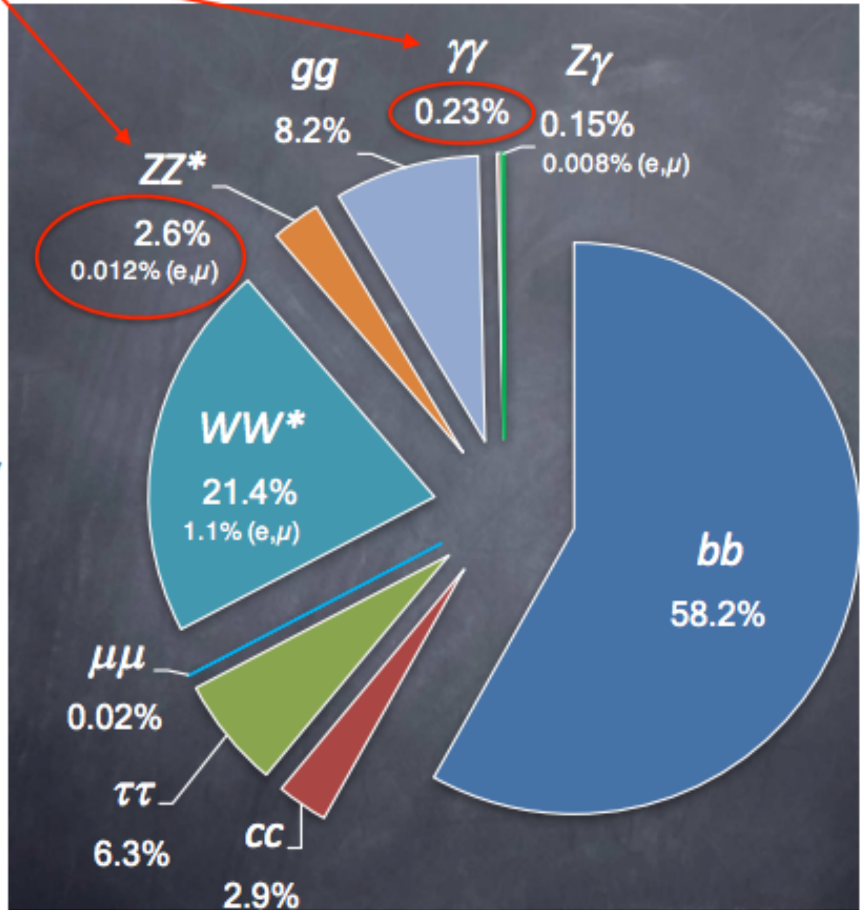
Higgs Decay

- H→bb is the Dominant Decay mode of Higgs Boson(58%)

ZZ, γγ: high mass resolution channels mass and precise differential measurements

WW: High BR, but low mass resolution

μμ: very small BR, but access to coupling to 2nd generation fermions

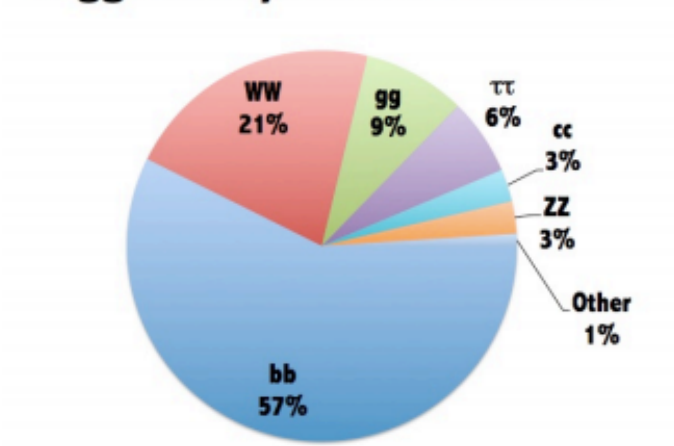


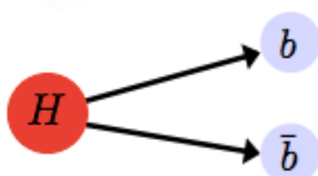
bb, ττ: high BR, but low S/B, important to directly probe Higgs boson coupling to fermions

Search for SM VBF H(bb)+γ

- Motivation: Search H→bb decay mode
  - largest branching ratio (~58%)

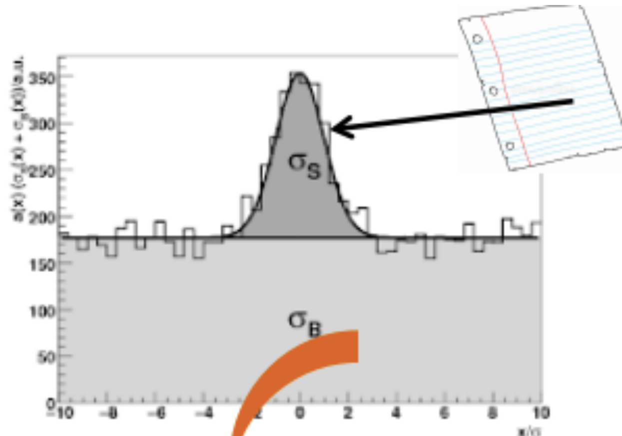
Higgs decays at m_H=125GeV

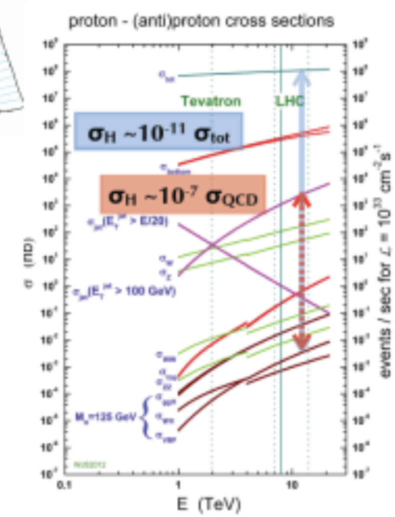




$$m_H = \sqrt{(p_b + p_{\bar{b}})^2}$$

Need to reconstruct an individual quark
Need to identify the flavor of the quark
SM background is 10 orders of magnitude higher





H→bb observation in ICHEP2018

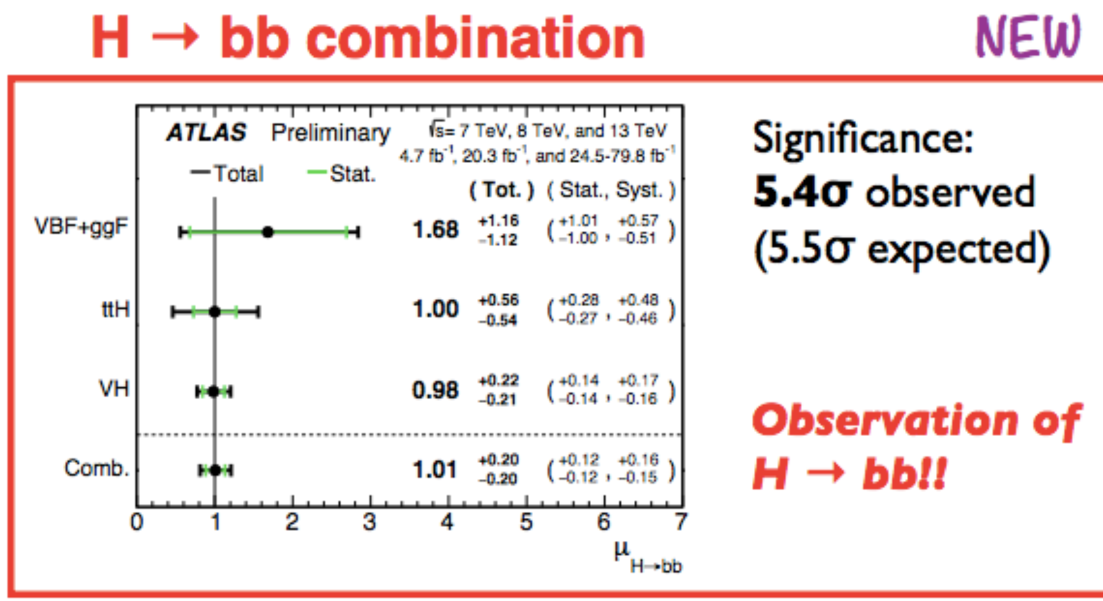
- ATLAS presented H→bb observation in ICHEP2018 (5.4σ)
- China Science Daily reported this news in its front page
  - NJU,USTC,SDU and SJTC made key contribution to VH(bb) analysis
  - IHEP made key contribution to VBF H(bb) analysis
- CMS confirmed H→bb observation in Vitnam2018 (5.6σ)


中国科学报
CHINA SCIENCE DAILY
总第7082期
2018年7月11日 星期三 今日8版

ATLAS 首次发现希格斯粒子最主要衰变过程
中国科学家作出关键贡献

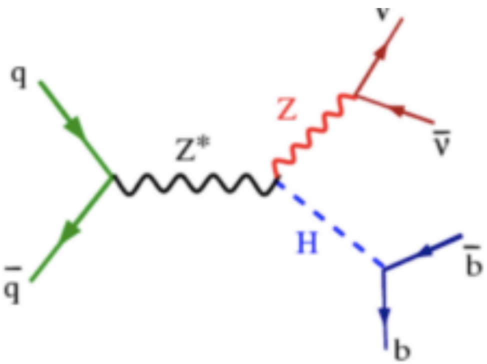
我国最大盐湖资源环境信息数据库建成
含有我国近千个盐湖基本数据

我国每万人口拥有10.6件发明专利

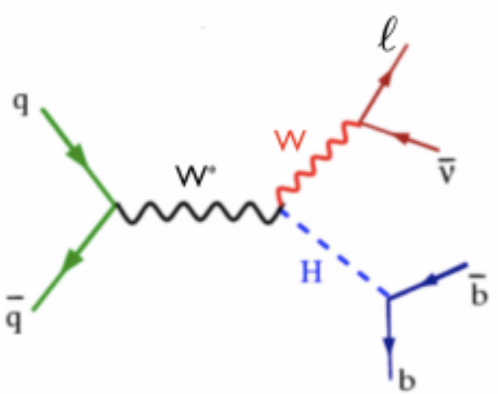


VH(bb) analysis

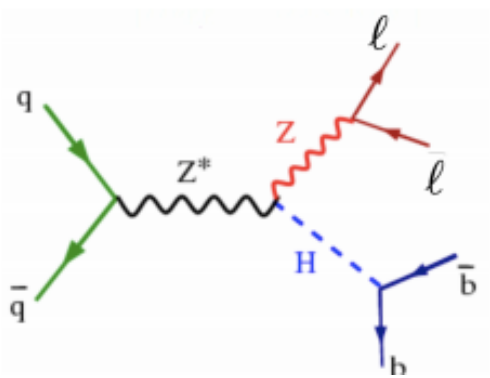
0-lepton



1-lepton

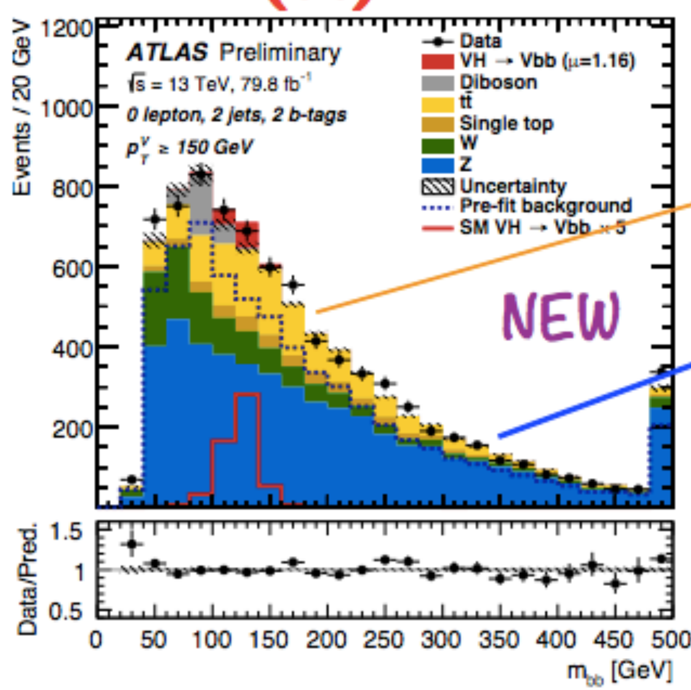


2-lepton



- VH production most sensitive mode for H → bb at the LHC
- 3 channels (0-, 1-, 2 charged leptons from V= W/Z boson)
- Select 2 b-tagged jets and $p_T(V)$ > 75 or 150 GeV
- Main discriminant variables m(bb), $p_T(V)$ and ΔR(bb) (combined into a Boosted Decision Tree)

m(bb)



Non-resonant backgrounds:

ttbar, single top

(NLO, PowHeg)

W+jets

Z+jets

(NLO for up to 2 extra jets, Sherpa 2.2.1)

Overall strategy: normalization from data, shapes from MC

VH(bb) result

Fit result with 79.8 fb^{-1} of Run-2 data

$\mu = \sigma_{meas}/\sigma_{SM} = 1.16^{+0.27}_{-0.25}$
Significance: **4.9σ** (4.3σ expected)

Combination with Run-1:

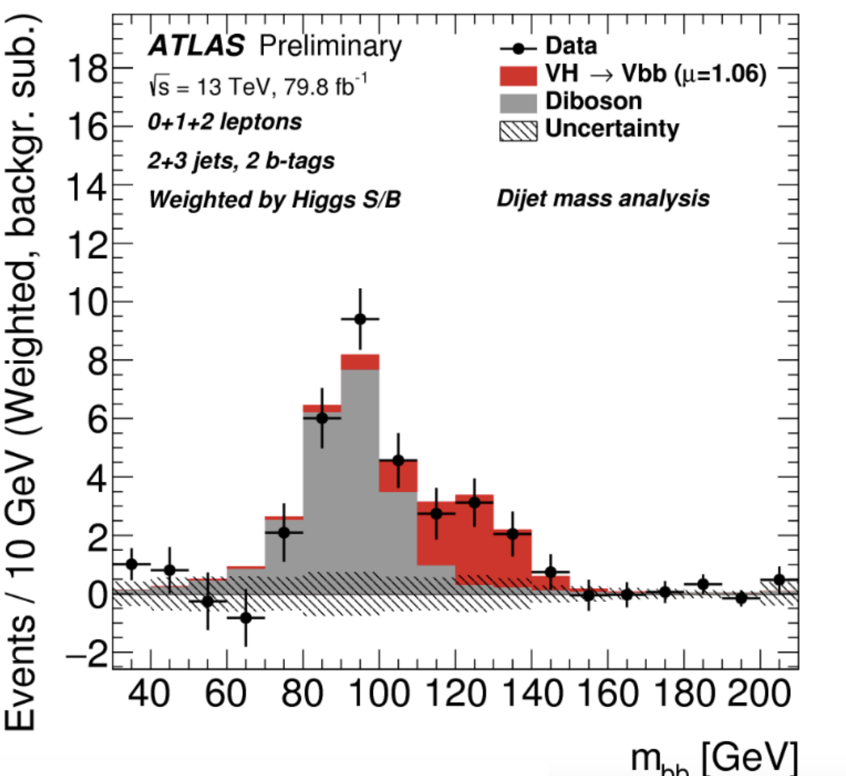
$\mu = 0.98 \pm 0.14(\text{stat.})^{+0.17}_{-0.16}(\text{syst.})$
Significance: **4.9σ** (5.1σ expected)

With VH(bb) from 2016/17 at 13 TeV, 77.2 fb^{-1}

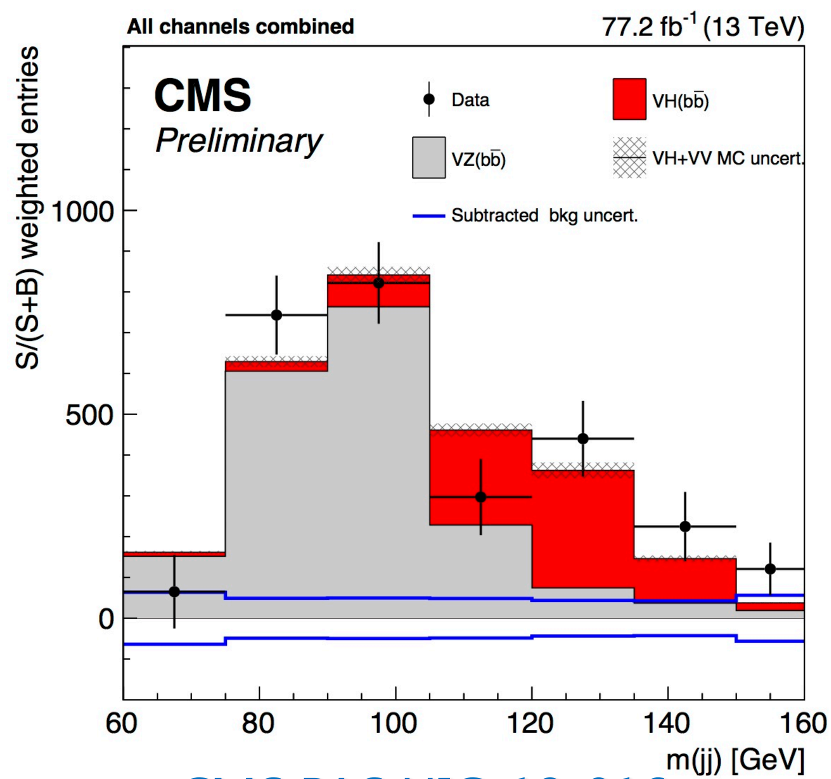
- **Significance: 4.4 σ obs (4.2 exp)**

With VH(bb) including also 7 and 8 TeV

- **Significance: 4.8 σ obs (4.9 exp)**



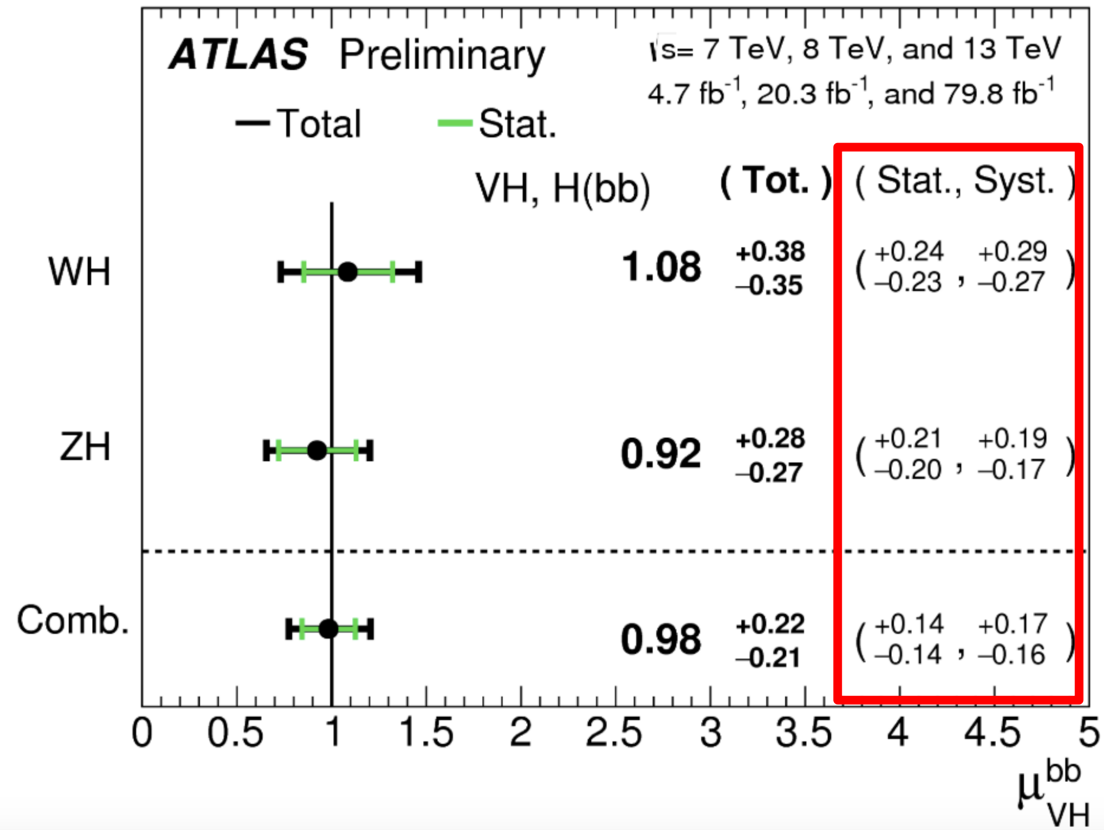
ATLAS-CONF-2018-036



CMS PAS HIG-18-016

VH(bb) major systematics

- Systematics uncertainty is comparable to statistics uncertainty
- Major systematics :
  - W+jet $p_T(W)$ modelling
  - m_{bb} shape in Z+jets
  - m_{bb} shape in diboson
  - Signal acceptance

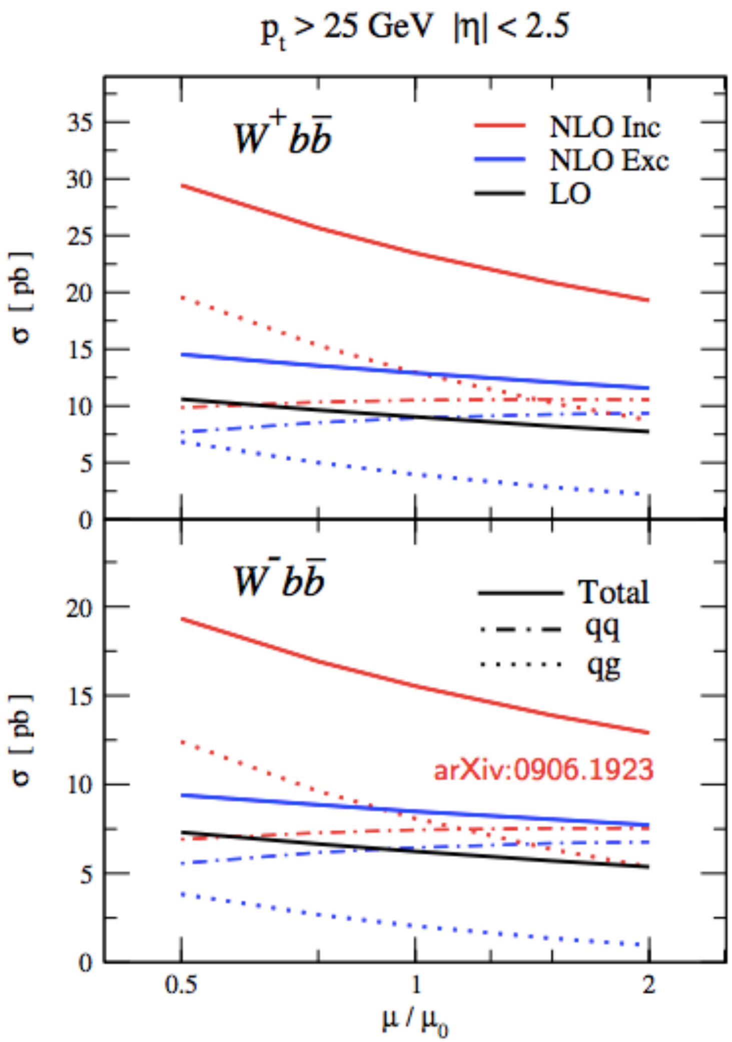


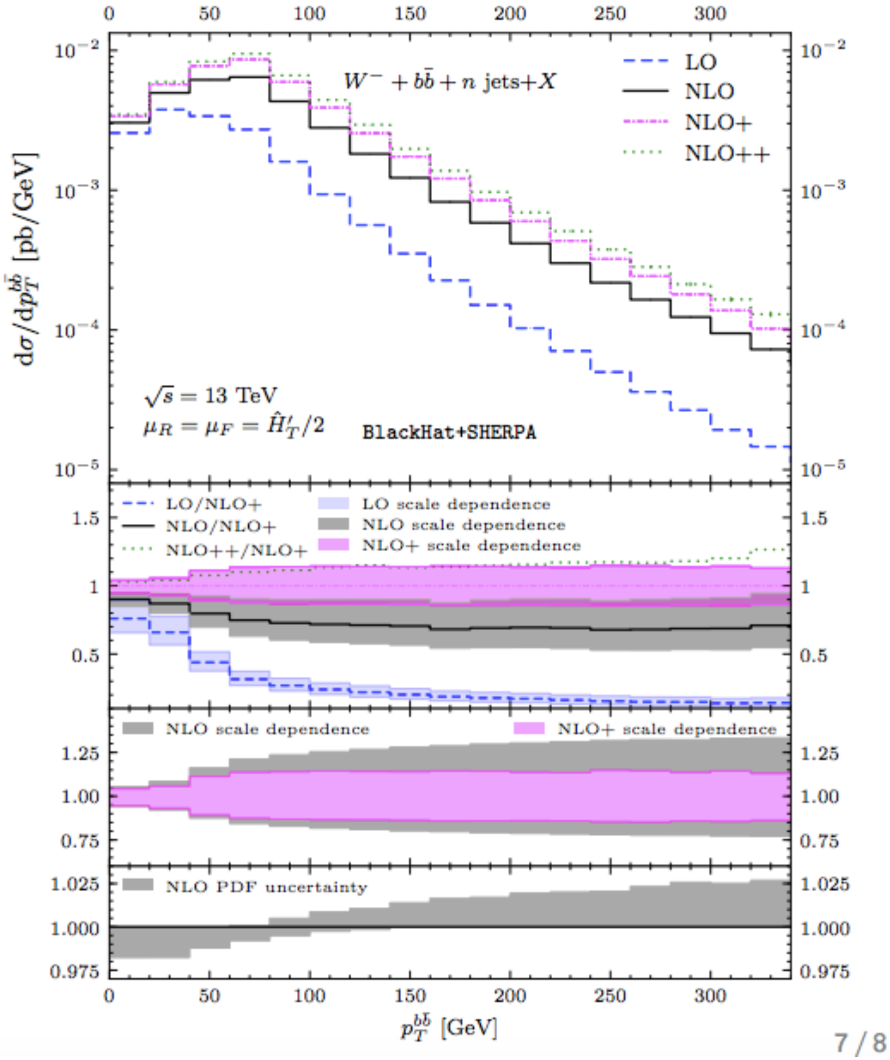
ATLAS-CONF-2018-036

VH(bb) major issue

- Large QCD scale uncertainty in W+bjets BG modelling
  - W+jet $p_T(W)$ modelling

[Anger, FFC, Ita, Sotnikov arXiv:1712.05721]

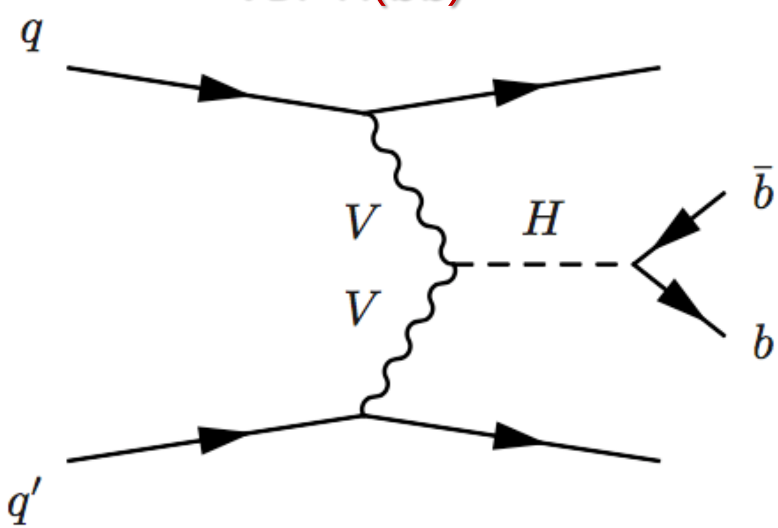




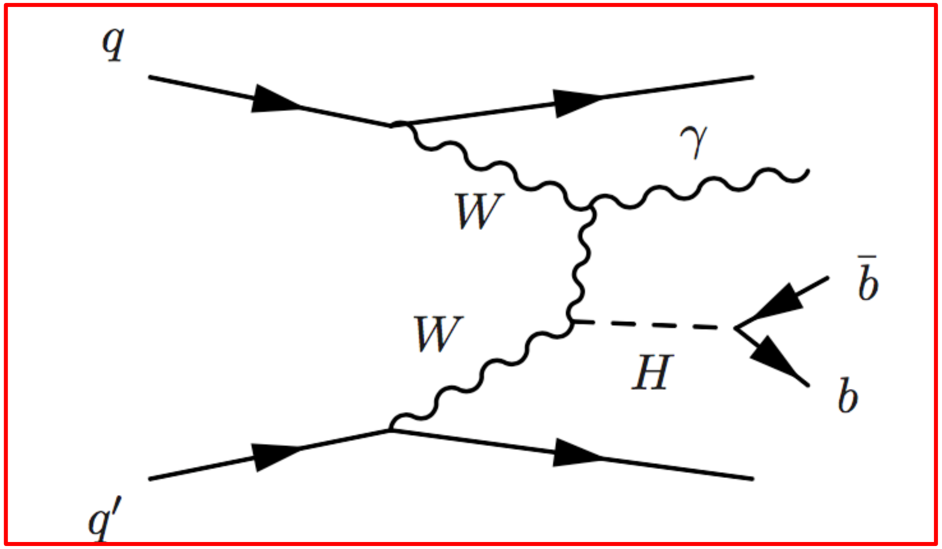
VBF H(bb) analysis

- IHEP team propose Search for H->bb 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

VBF H(bb)



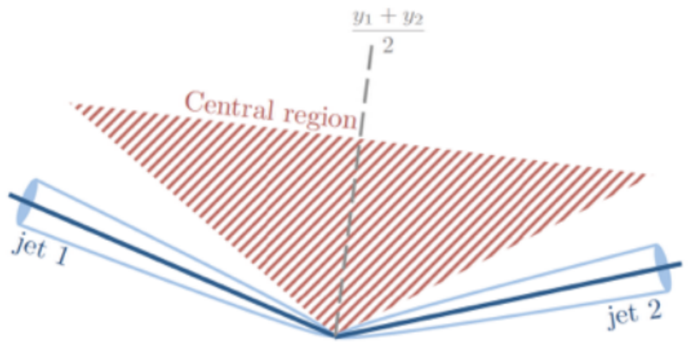
VBF H(bb) +γ



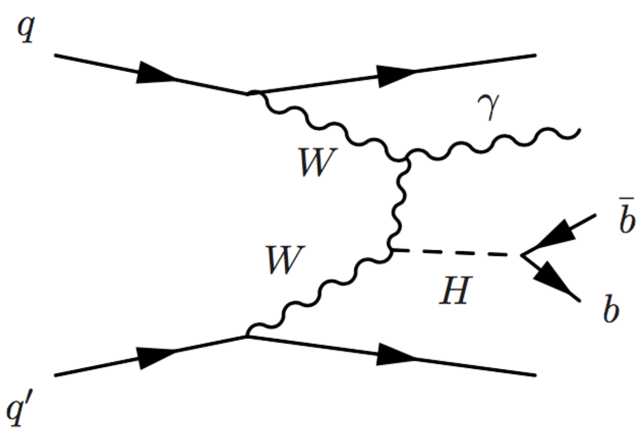
MVA Input variable: photon centrality

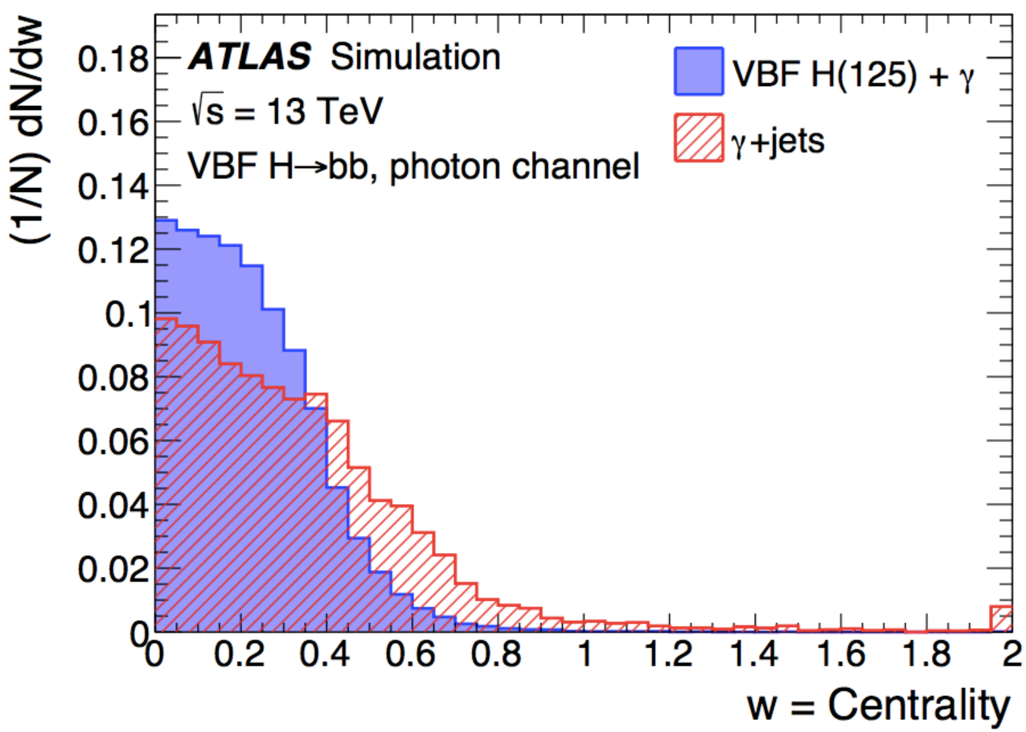
Use 11 variable used in BDT analysis

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



No color connection between VBF jets and b jets in signal



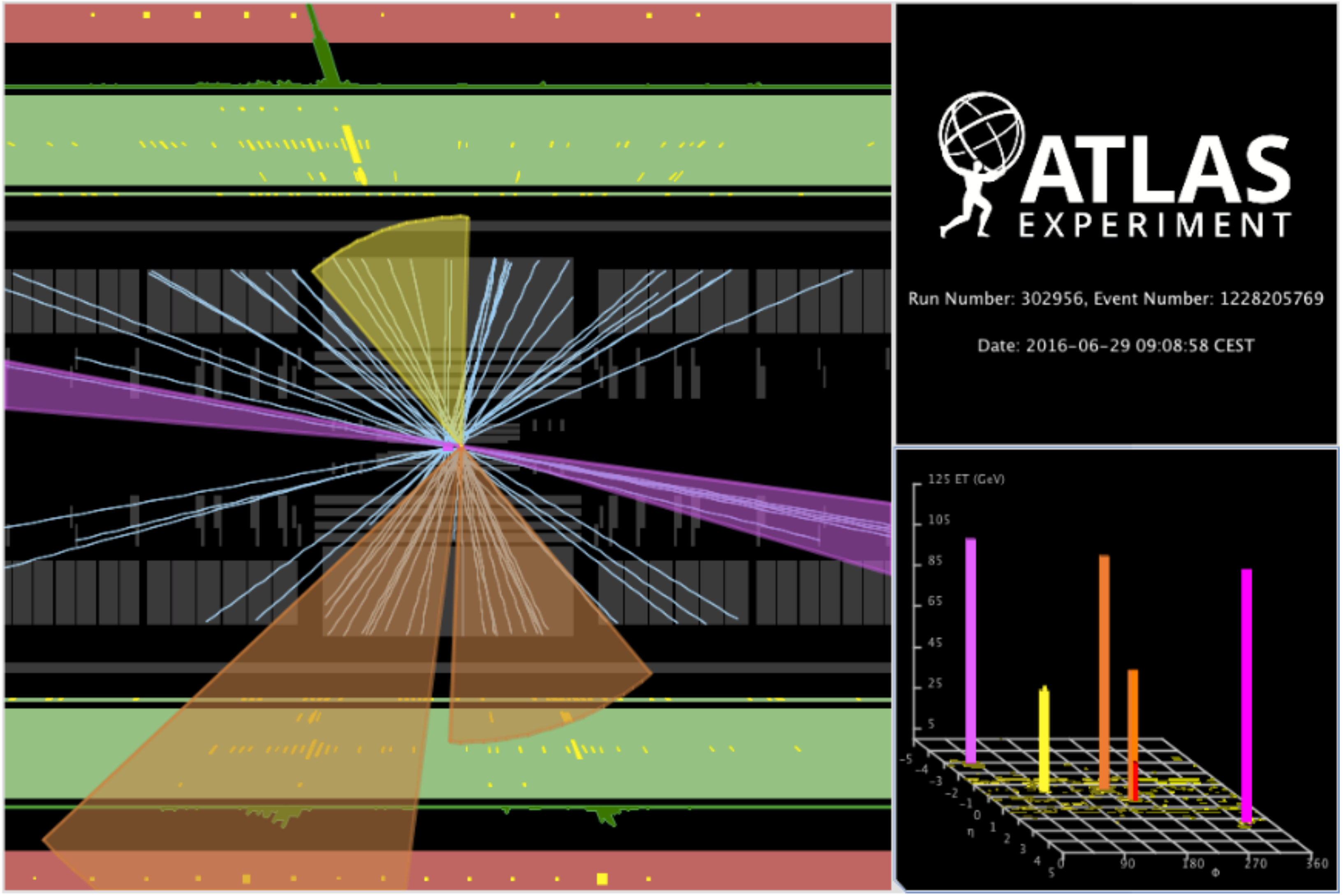


Event display for VBF H(bb)

Photon

VBF jets

b-jets

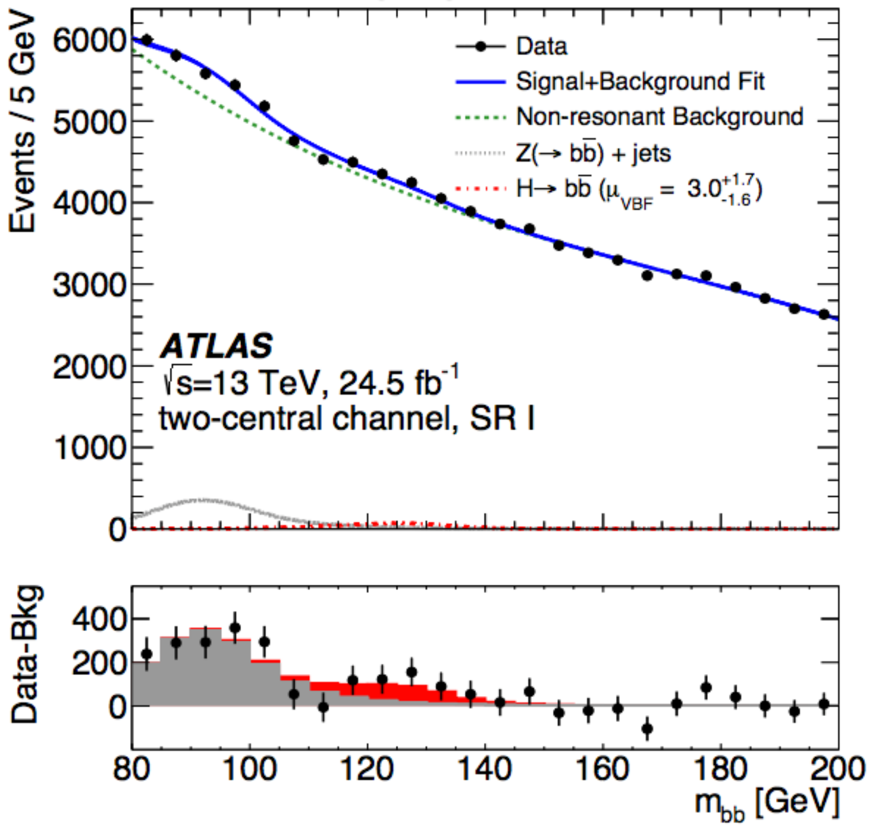


VBF H(bb) background fit

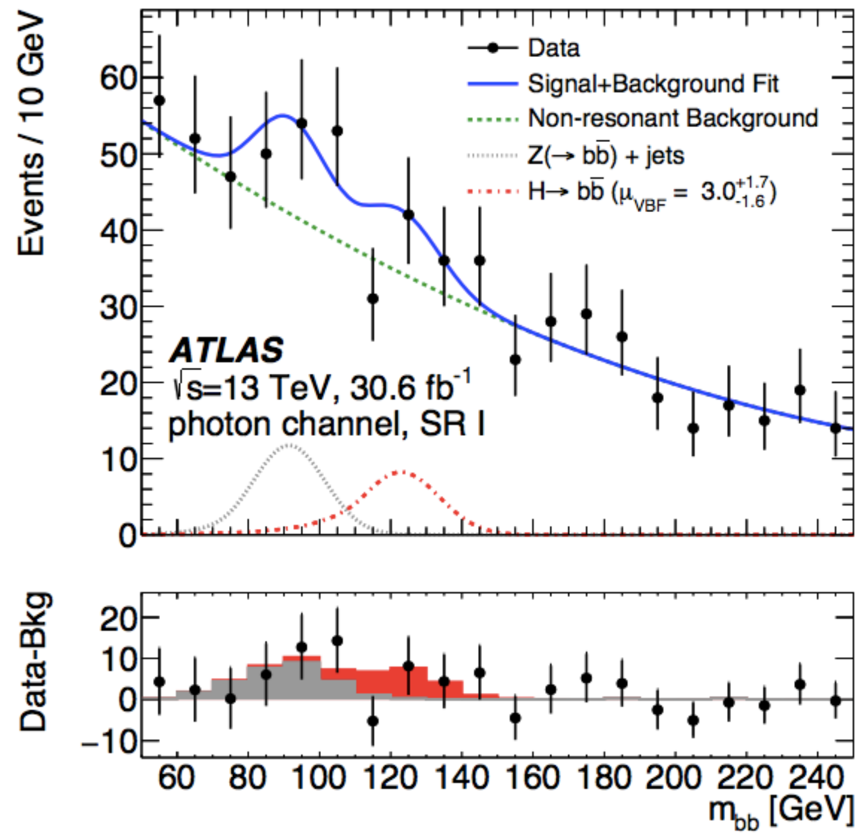
- Simultaneous m(bb) Fit to all 9 regions
  - Signal shape is modelled by crystal ball function
  - Background shape is modelling by polynomial function

arXiv:1807.08639

VBF H(bb)



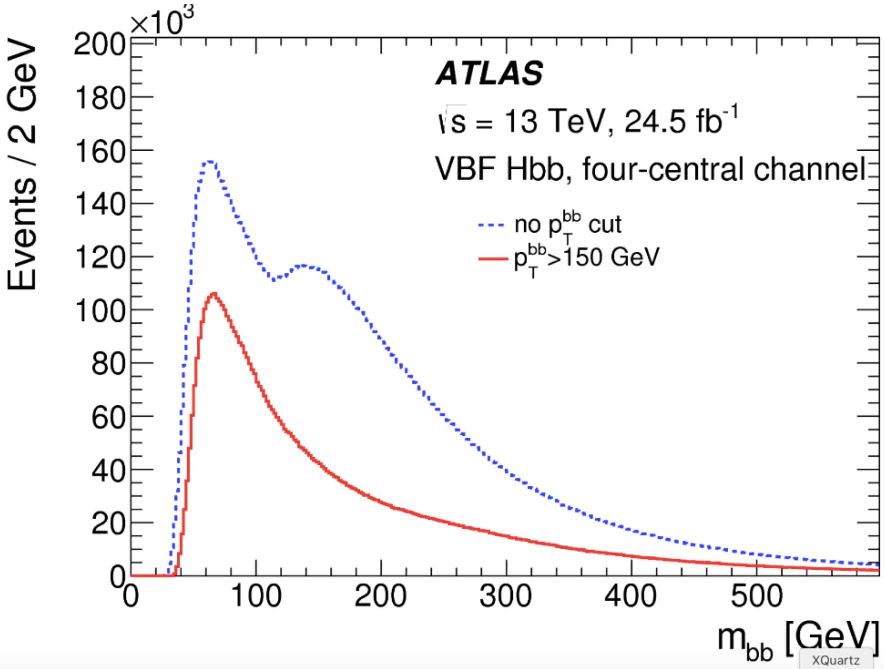
VBF H(bb) $+\gamma$

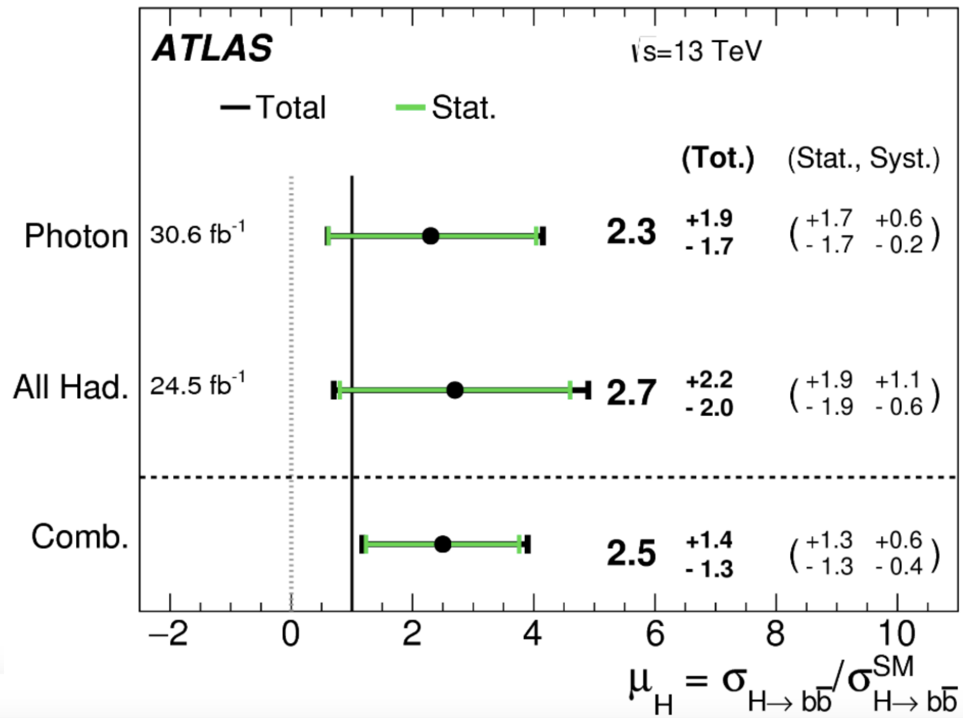


VBF H(bb) result and major issue

- ~2σ significance using VBF H(bb)
  - Statistics uncertainty dominated
- 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

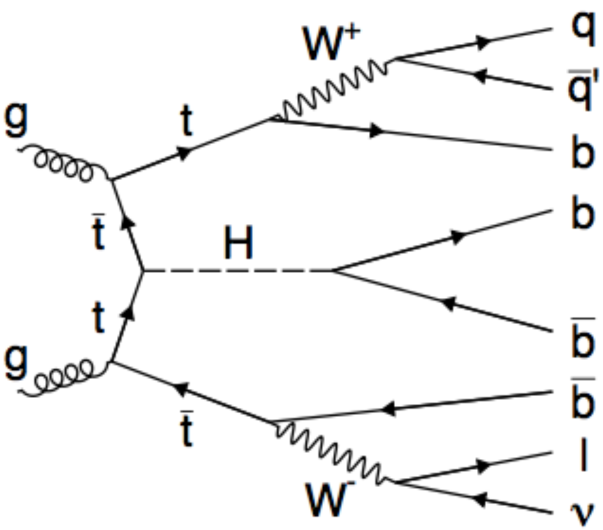
arXiv:1807.08639

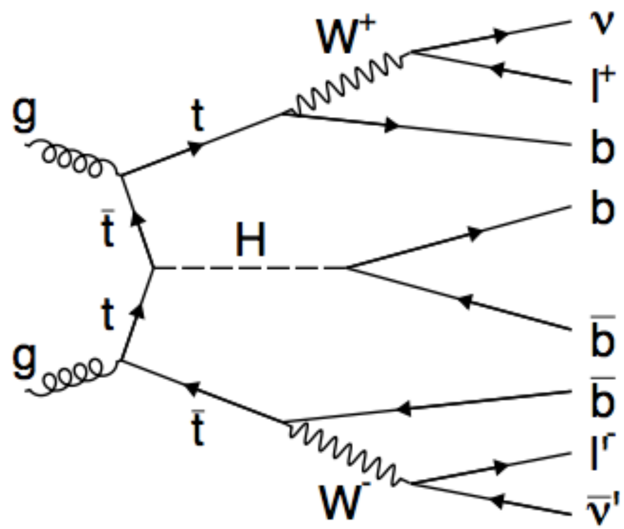




ttH(bb)

Phys. Rev. D 97 (2018) 072016





Single Lepton Channel

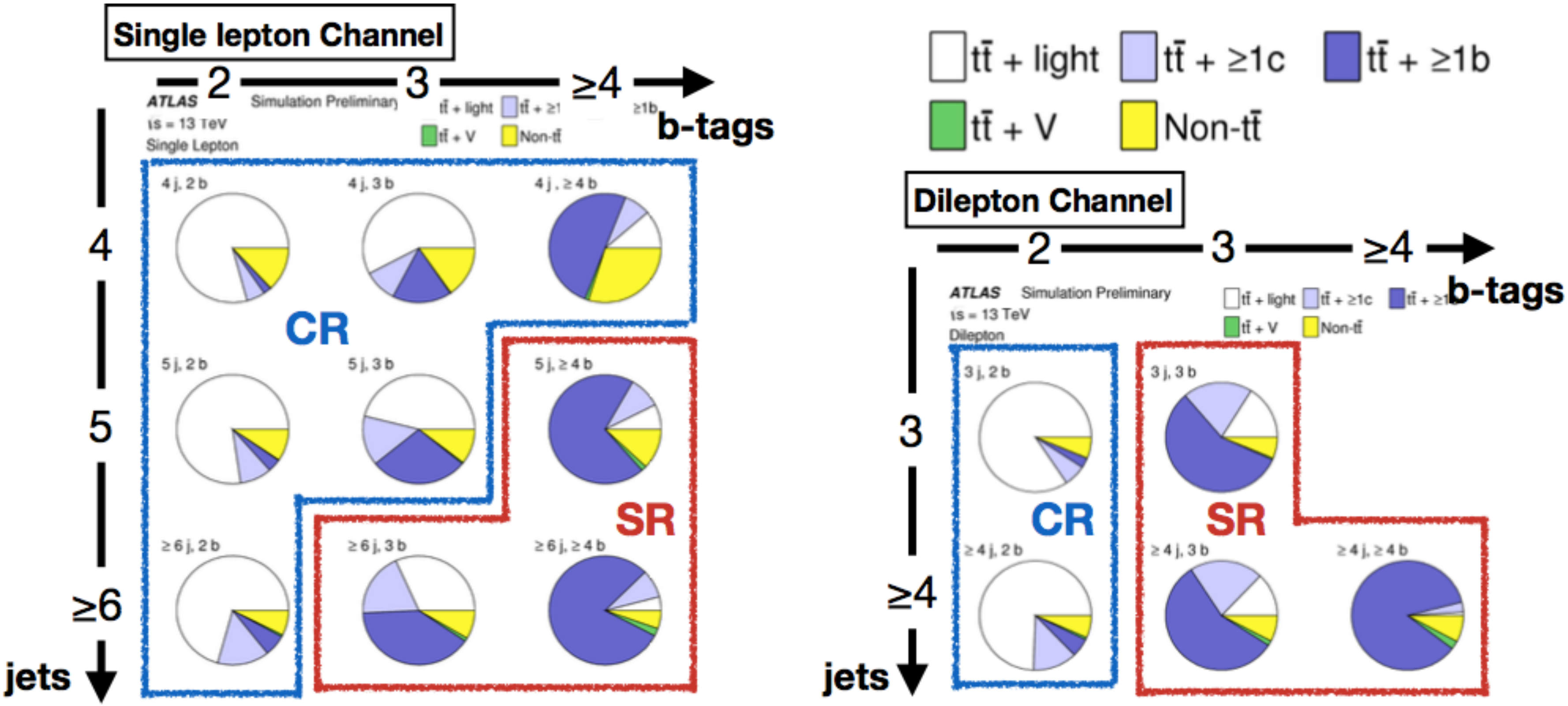
- 1 light lepton (e,μ)
- At least 4 jets
- At least 2 b-tagged jets

Dilepton Channel

- 2 opposite charge light leptons (e,μ)
- At least 3 jets
- At least 2 b-tagged jets
- Z mass veto

ttH(bb)

Phys. Rev. D 97 (2018) 072016



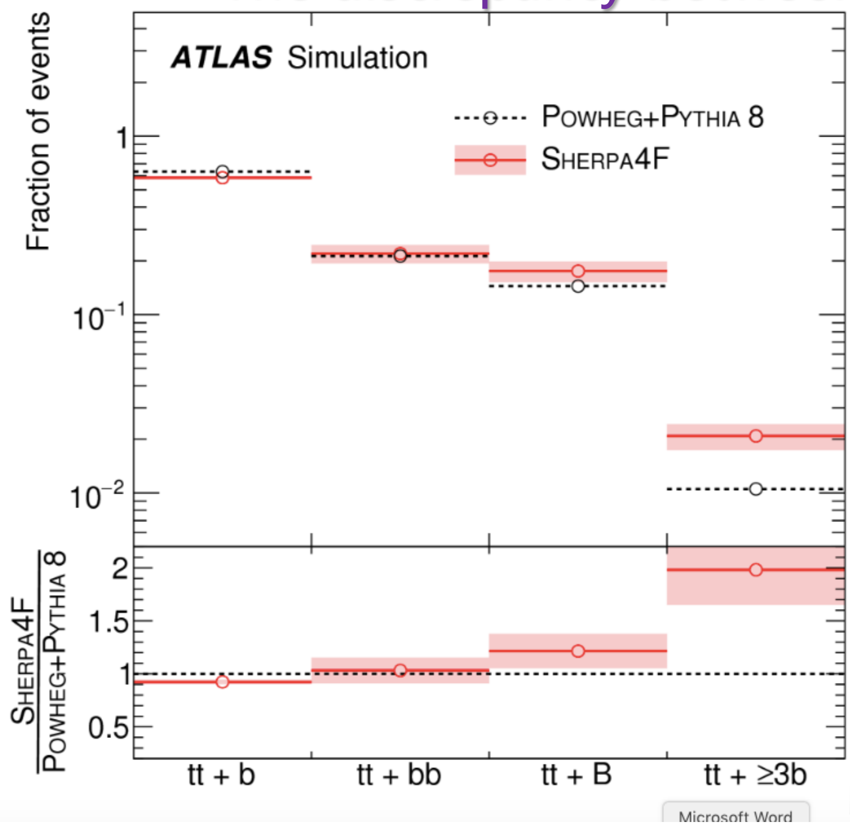
Signal Region (SR) : Enriched in signal.

Control Region (CR) : Use to constraint backgrounds.

tt + ≥1 bjet, tt + ≥1 cjet, and tt + light jets are the dominant backgrounds

ttH(bb)

- 1.4σ significance using ttH(bb)
  - Systematics uncertainty dominated
- Major systematics:
  - ttbar+bb background modelling systematics
  - The discrepancy between Sherpa 4 flavor scheme and Powheg



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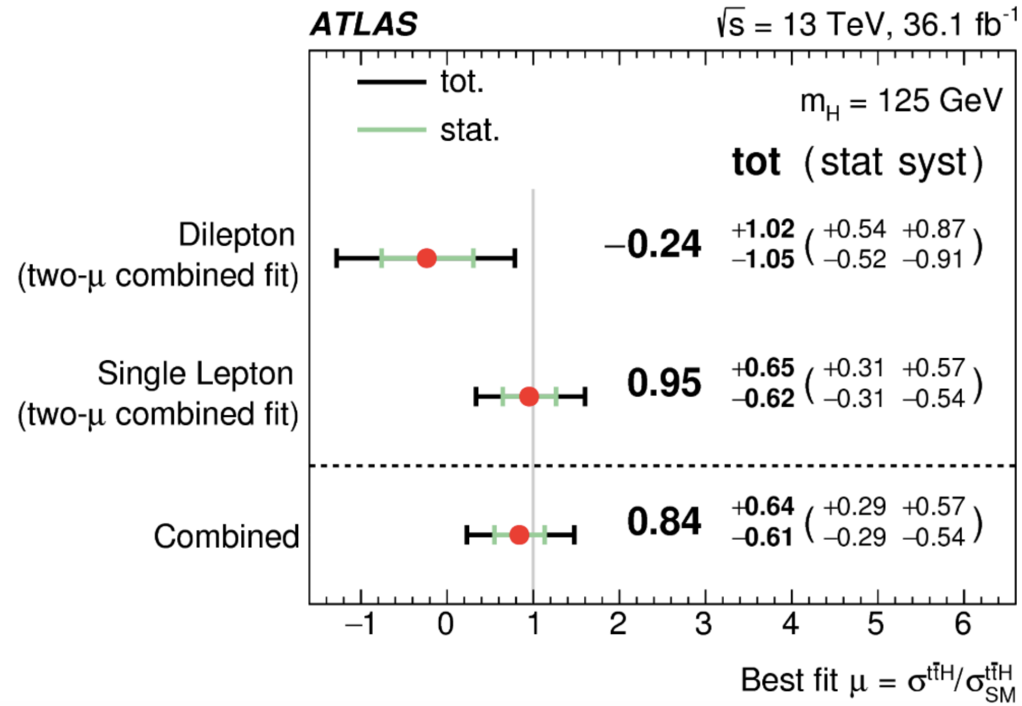
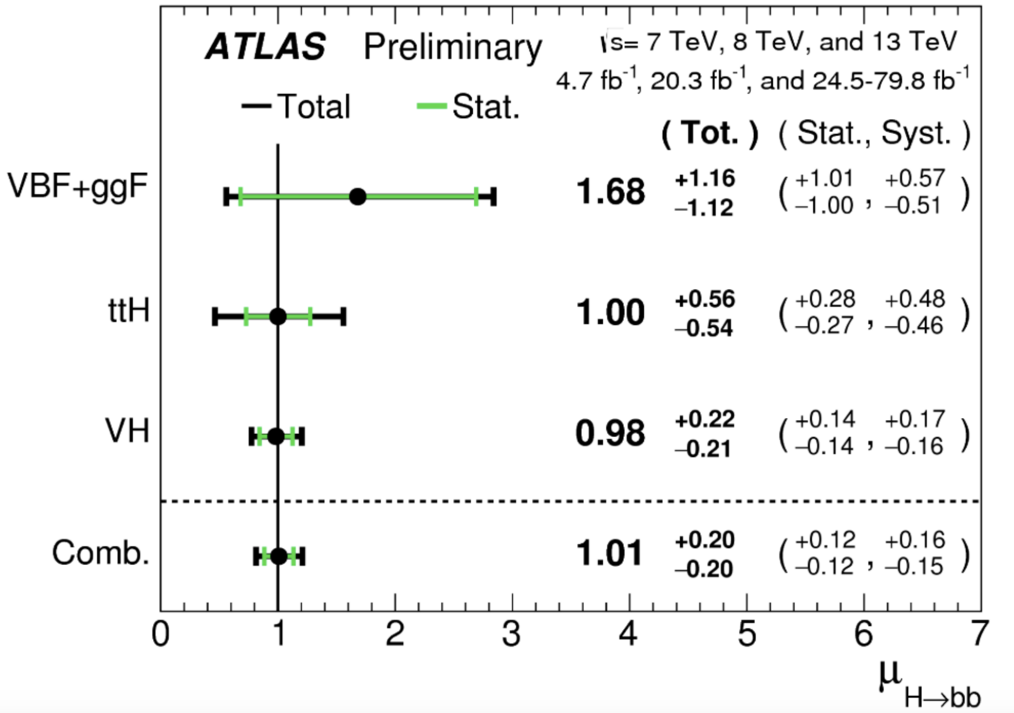
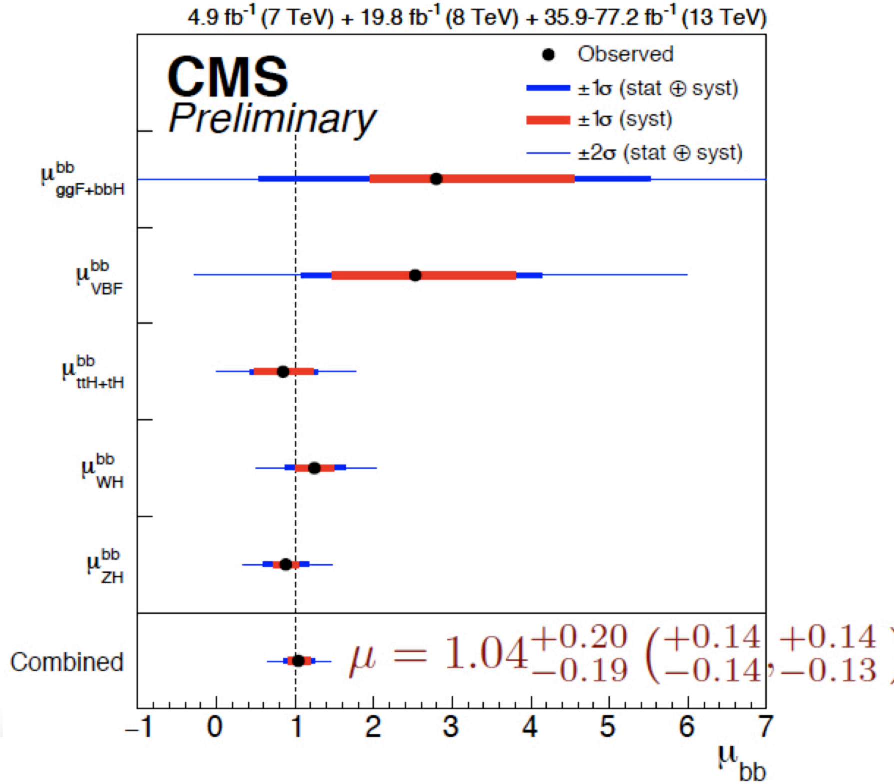


H->bb Combination

ATLAS Hbb (Run1+Run2): 5.4 σ (5.5 σ exp.)

CMS Hbb (Run1+Run2): 5.6 σ (5.5 σ exp.)

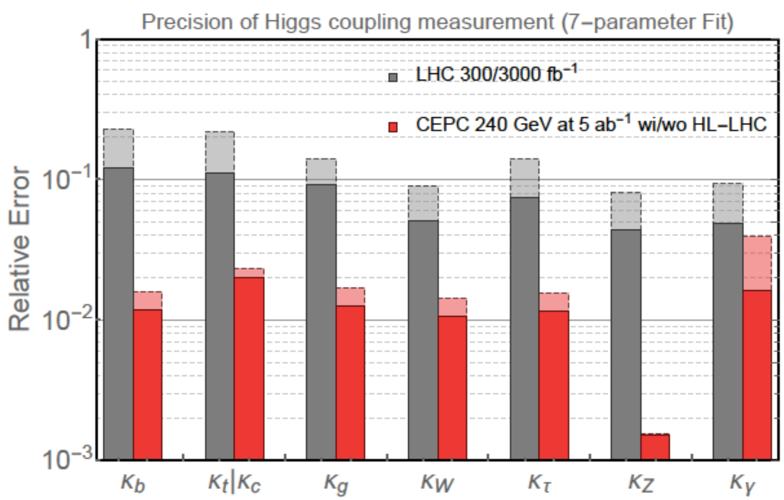


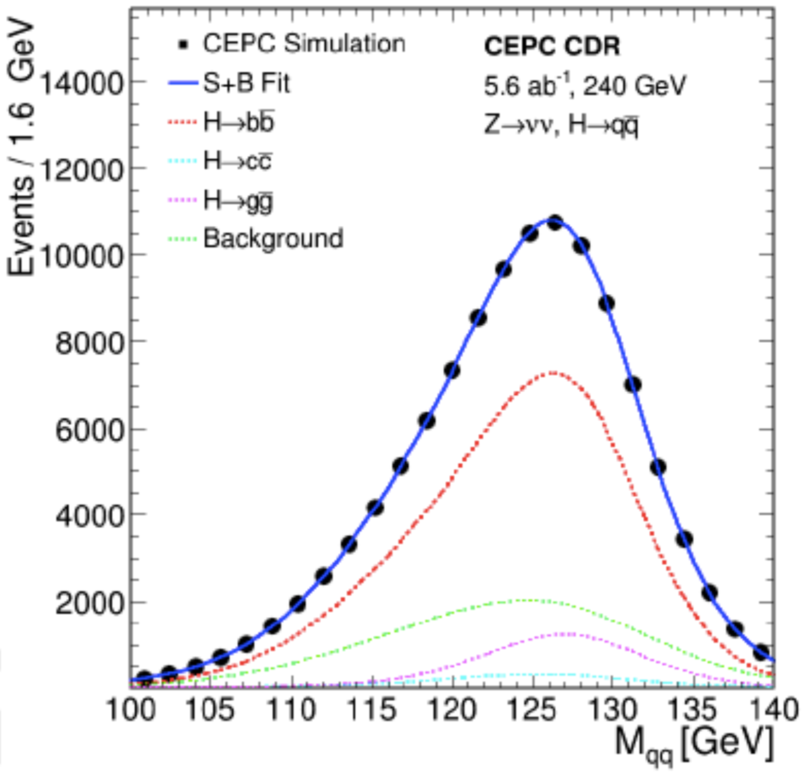


H->bb measurement in the future

- Current LHC precision is about 20%
- HL-LHC can measure H->bb to 10% level.
  - H->cc and H->gg are not likely be observed in LHC
- CEPC can improve H->bb measurement by two order of magnitude.
  - 0.3% level for H->bb, 3% for H->cc, 1% for H->gg.

Precision	CEPC	HL-LHC
H->bb	0.3%	~10%
H->cc	~3%	NA
H->gg	~1%	NA



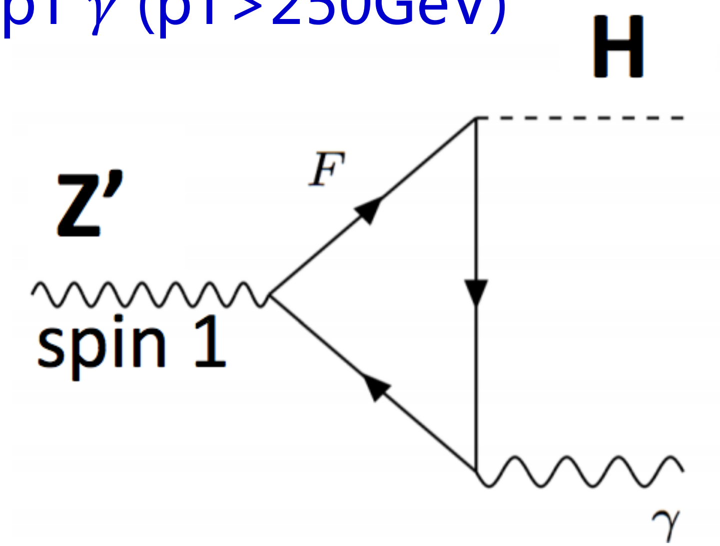


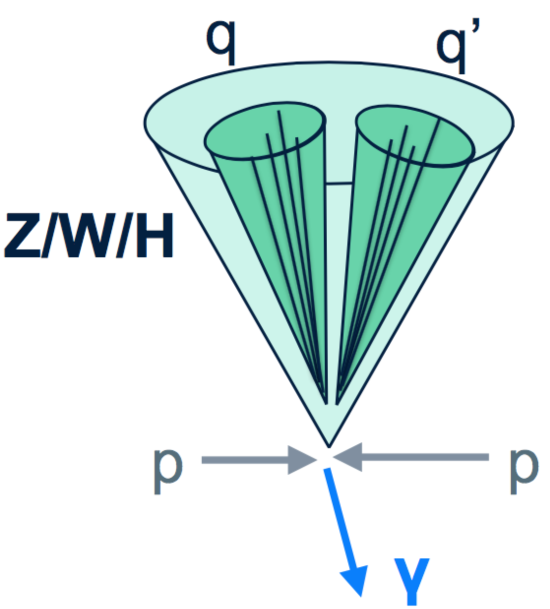
Outline

- Search for SM H→bb (Dominant Decay Channel)
  - VBF H→bb analysis
  - VH(→bb)
  - ttH(bb)
- BSM search with H->bb final state

Introduction search for X-> H(bb)γ

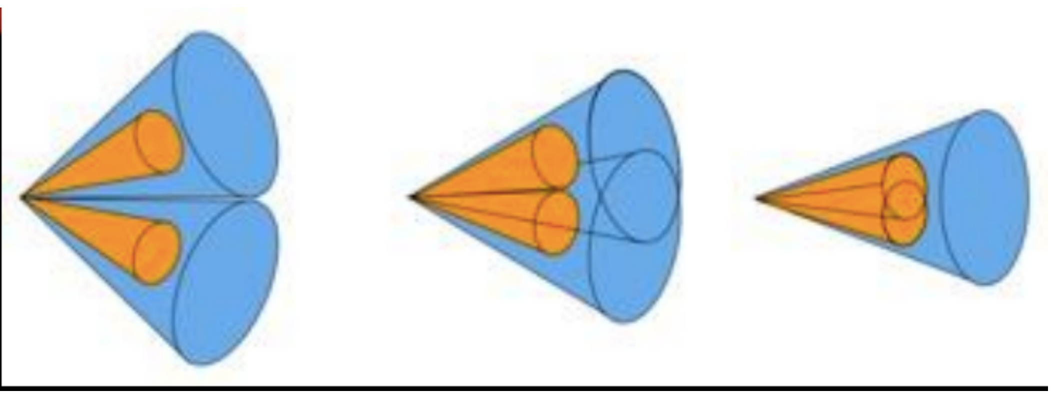
- Motivation
  - According to Liantao yesterday, V+H search is very promising
  - Search for anomalous magnetic moments of H (or W/Z)
  - Several models predict a new massive scalar decaying into Hγ
- Event selection :
  - boosted jet (b tagging) -- from H, W or Z decay
  - high pT γ (pT>250GeV)

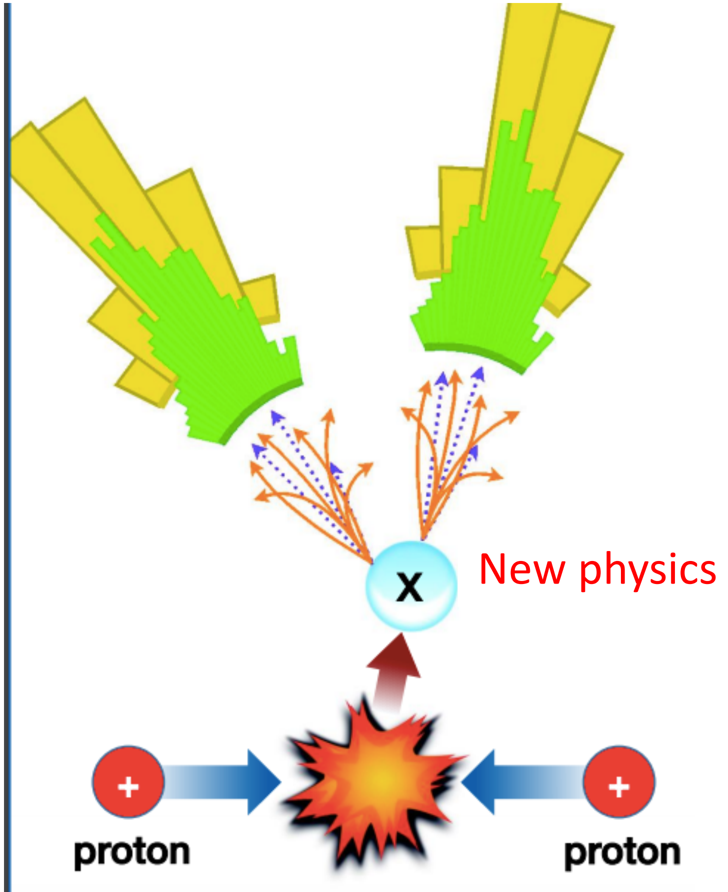




Key issue in VH inTeV scale

- Two b jets from boosted Higgs decay merge into one
- Difficult to reconstruct Higgs boson in jet final state
- Two new analysis technique used in this analysis
  - **B tagging on track jets**
  - **Jet substructure**

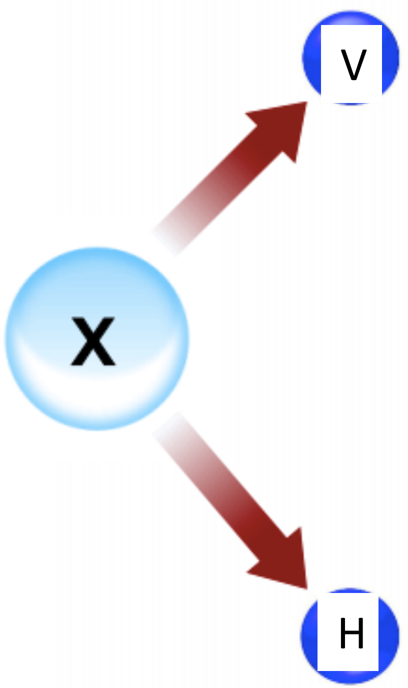


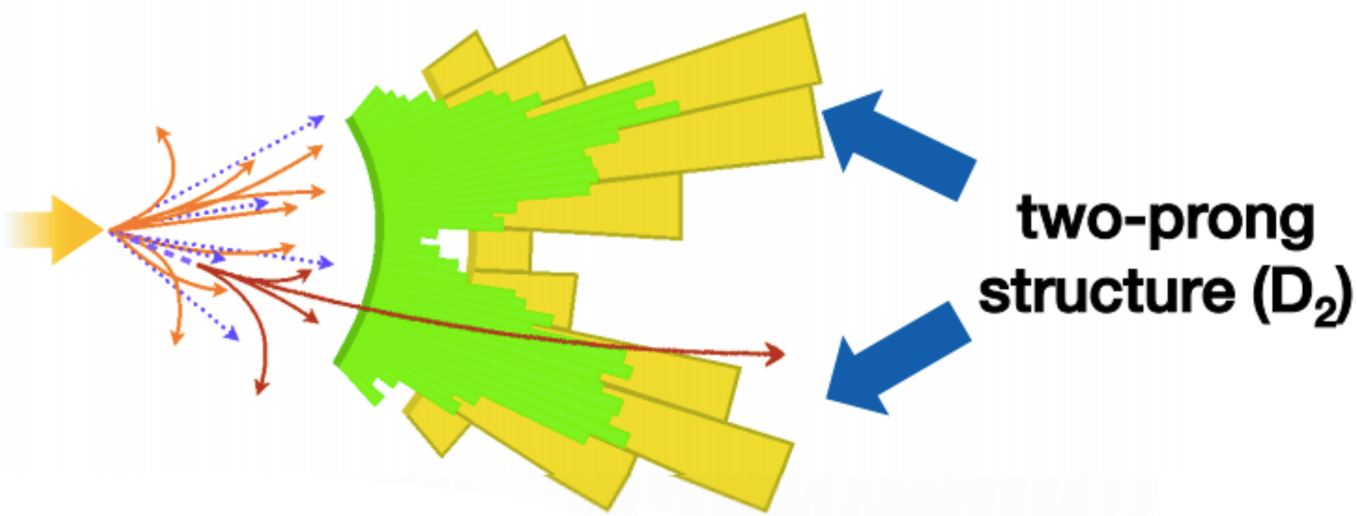


Jet Substruture

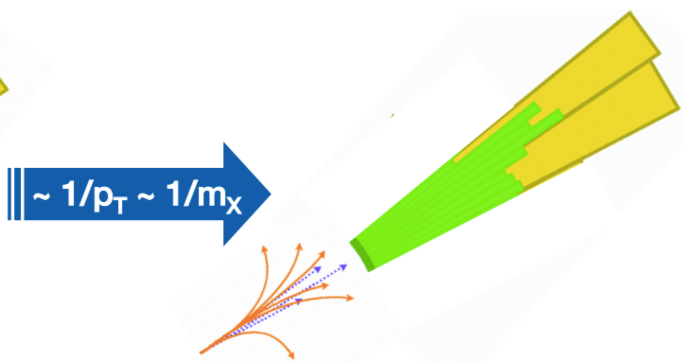
Jet substructure crucial tool for:

- Inclusive search for and measurement of H→bb in boosted regime.
- Searches for heavy (>1 TeV) resonances decaying to SM-bosons, or top-quarks.
- Precision measurements of SM in extreme phase-spaces.





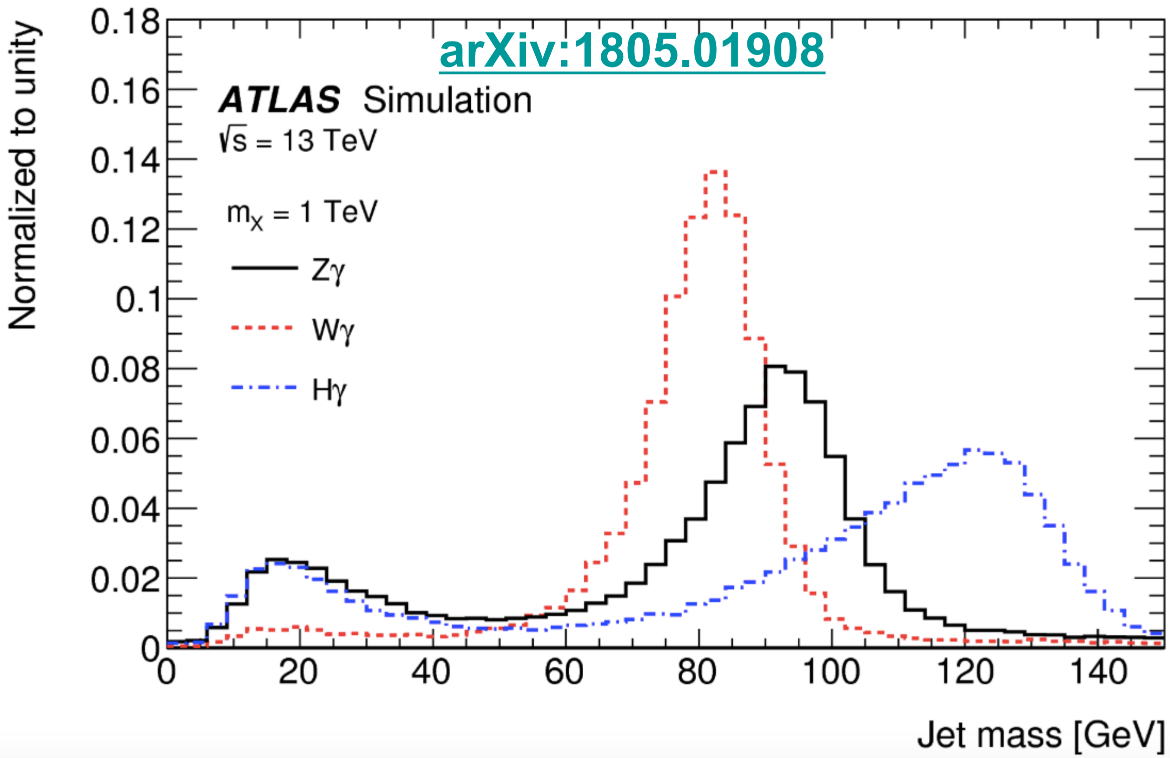
Jet mass



jet mass:

$$m^{\text{calo}} = \sqrt{\left(\sum_{i\in J} E_i\right)^2 - \left(\sum_{i\in J} \vec{p}_i\right)^2}$$

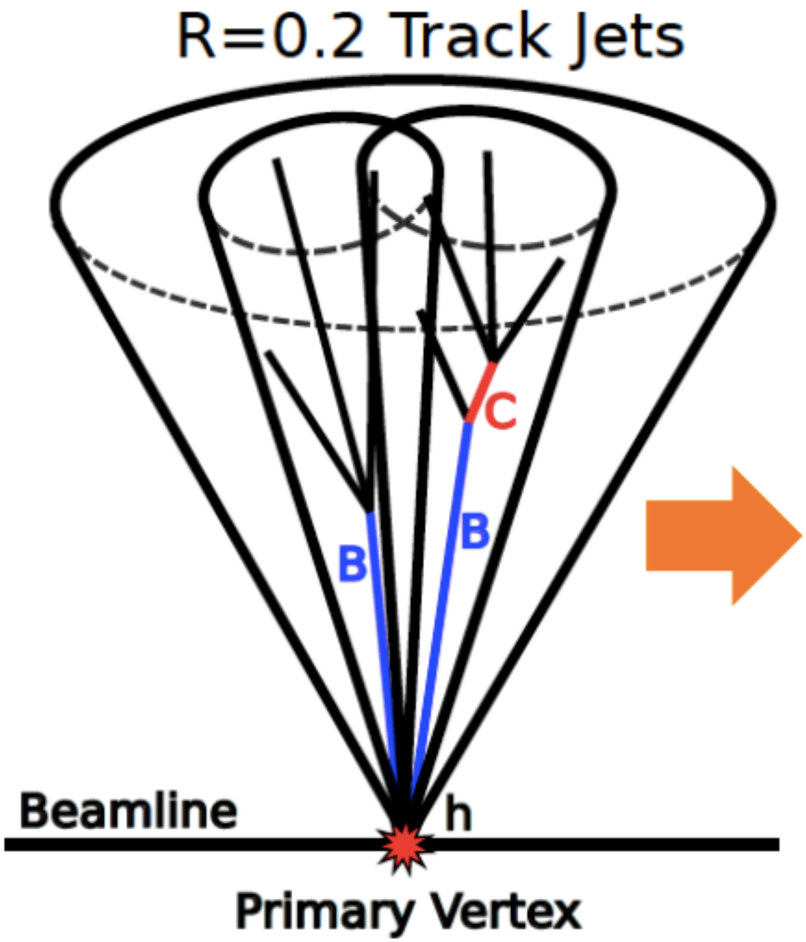
Reconstructed boosted H, Z and W boson



B tagging on track jet

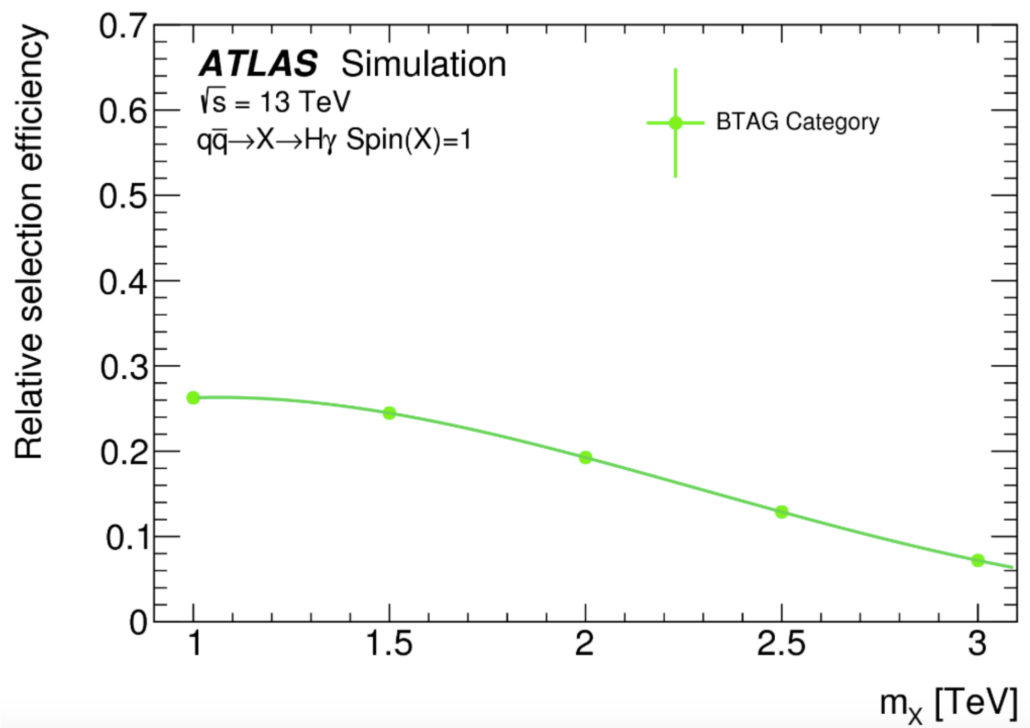
- B tagging based on track jet

Track jets overlapping for Higgs with very high momentum



Significant efficiency loss for resonance with higher mass

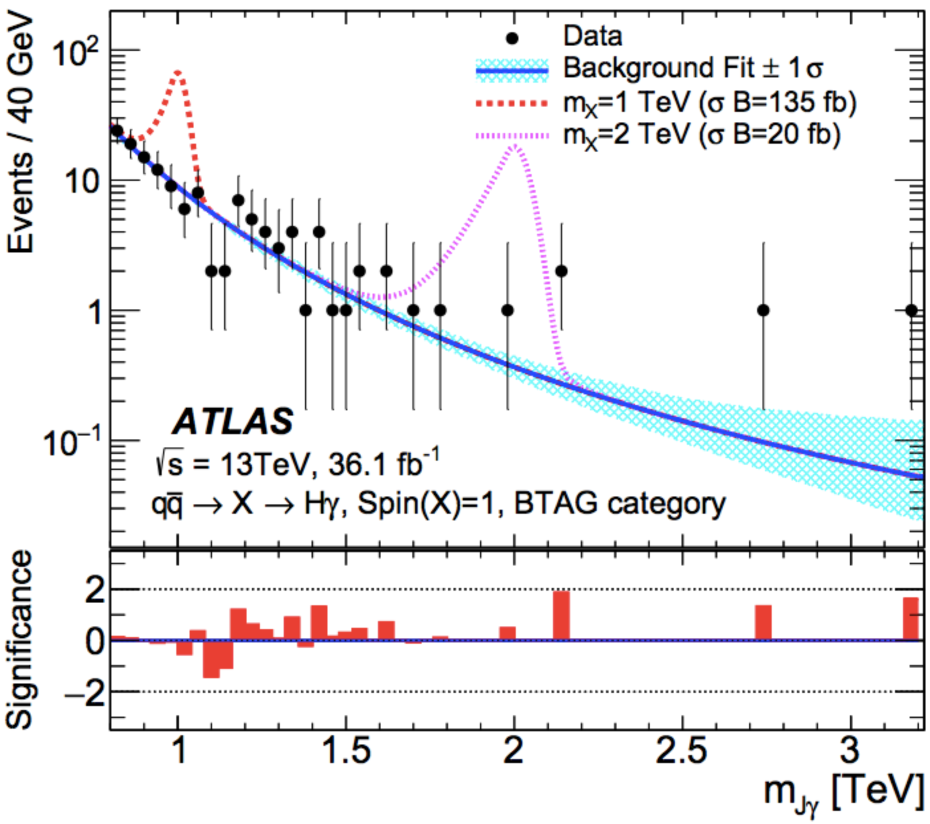
[arXiv:1805.01908]()

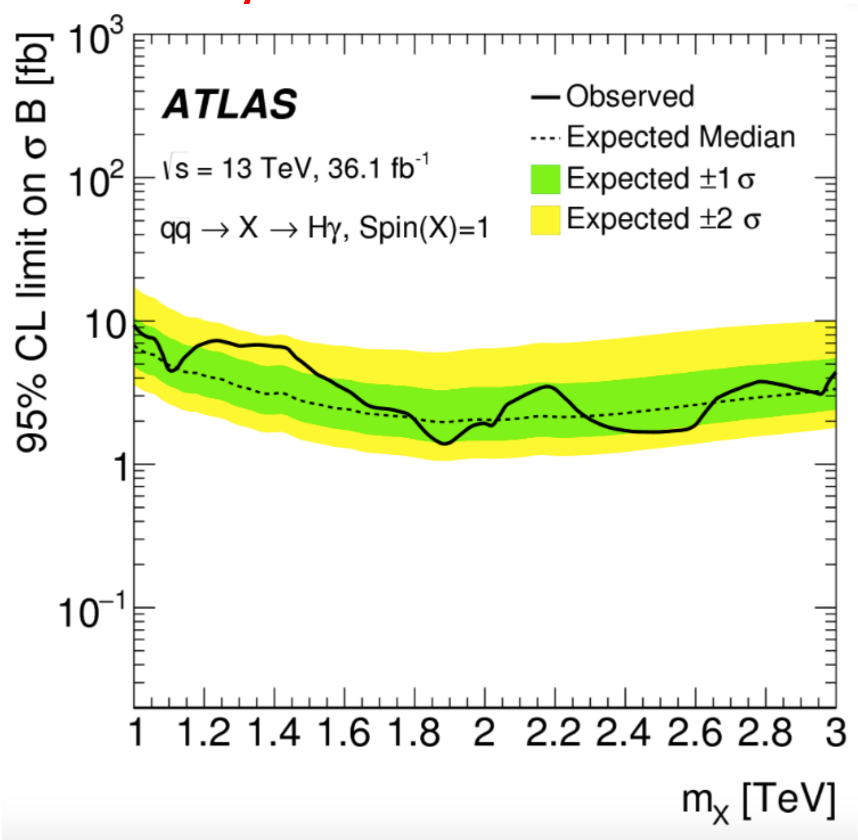


Limit setting of X-> Hγ search

- Use analytic function to fit fast falling background from
  - γjets, Zγ, SM VBF Hγ
- The first X-> Hγ limits (from 1TeV to 3TeV)
- IHEP/TDLI played a leading role in this analysis

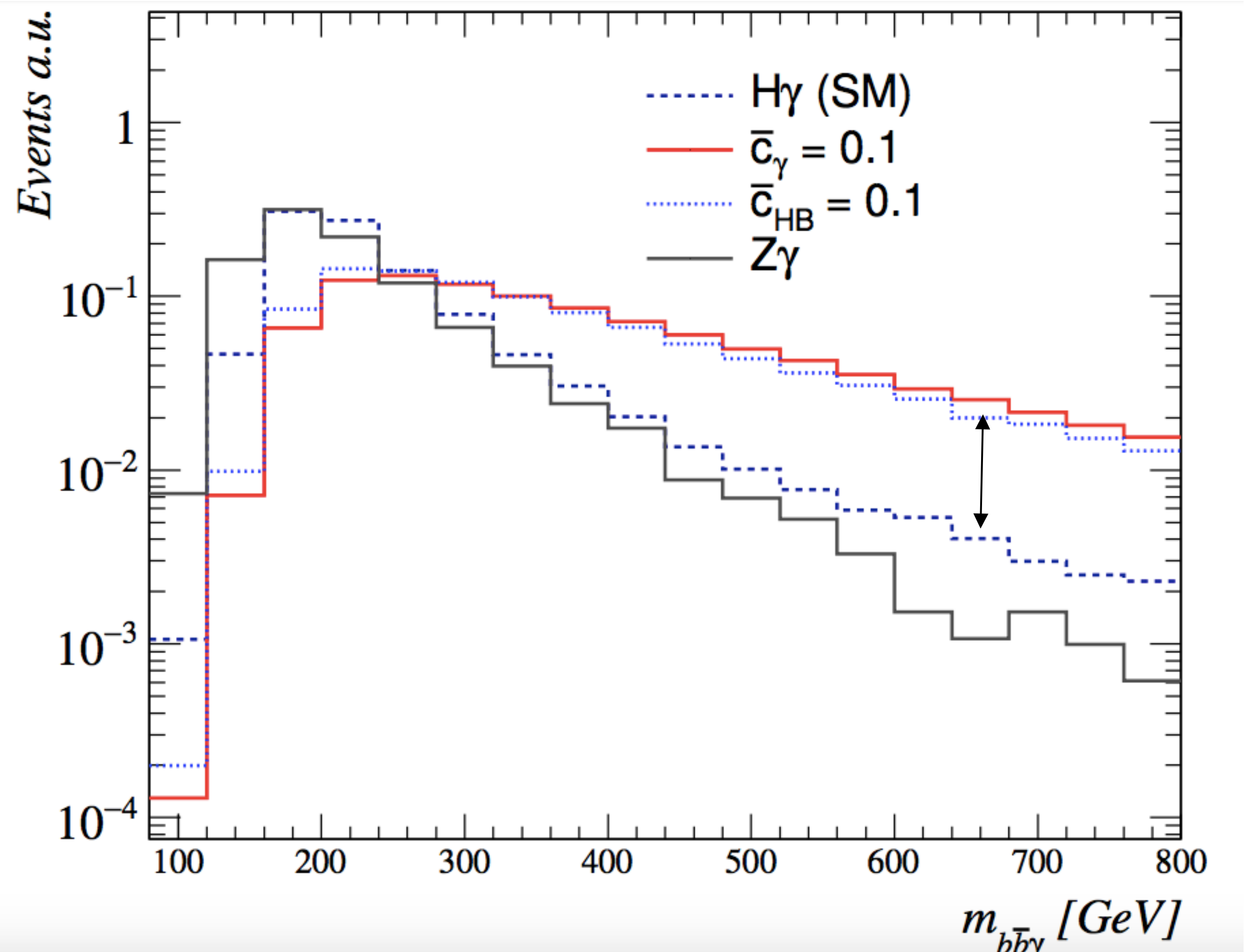
arXiv:1805.01908





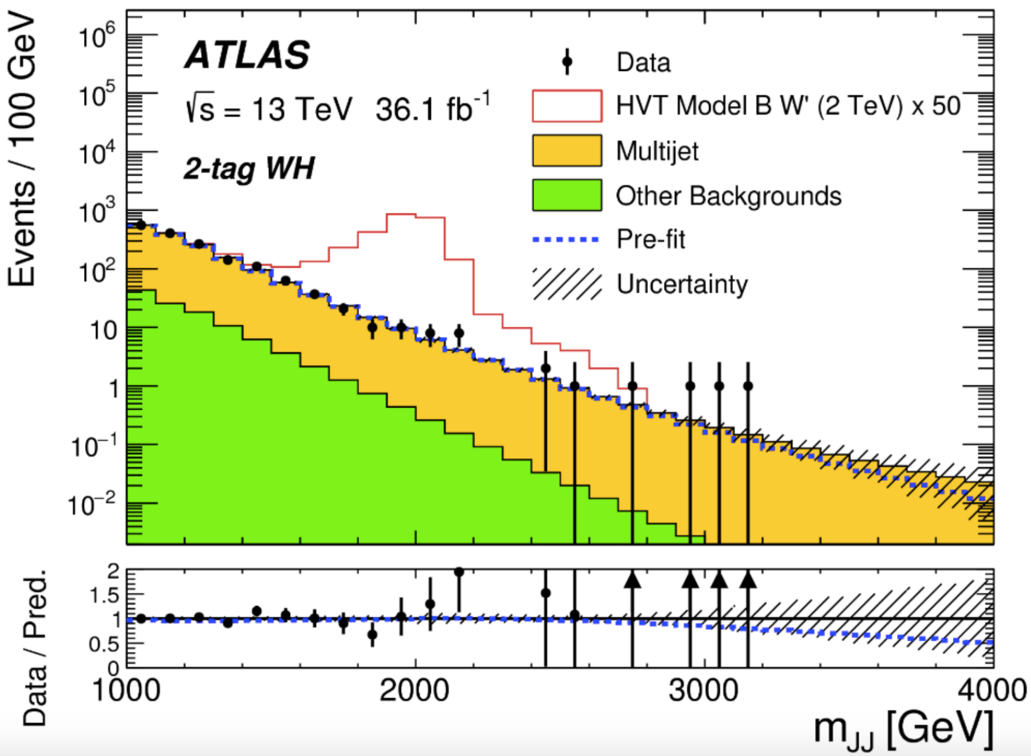
X-> Hγ search

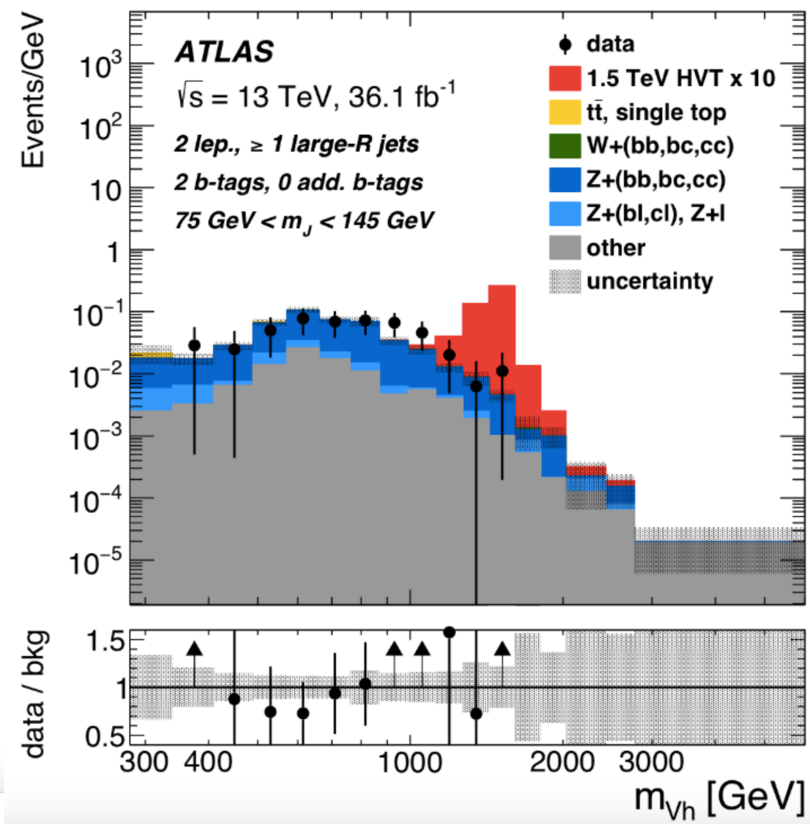
- Hγ mass spectrum can also be used for Higgs coupling study
  - strongly interacting light Higgs (SILH) model as an example



X-> VH search

- No new physics yet

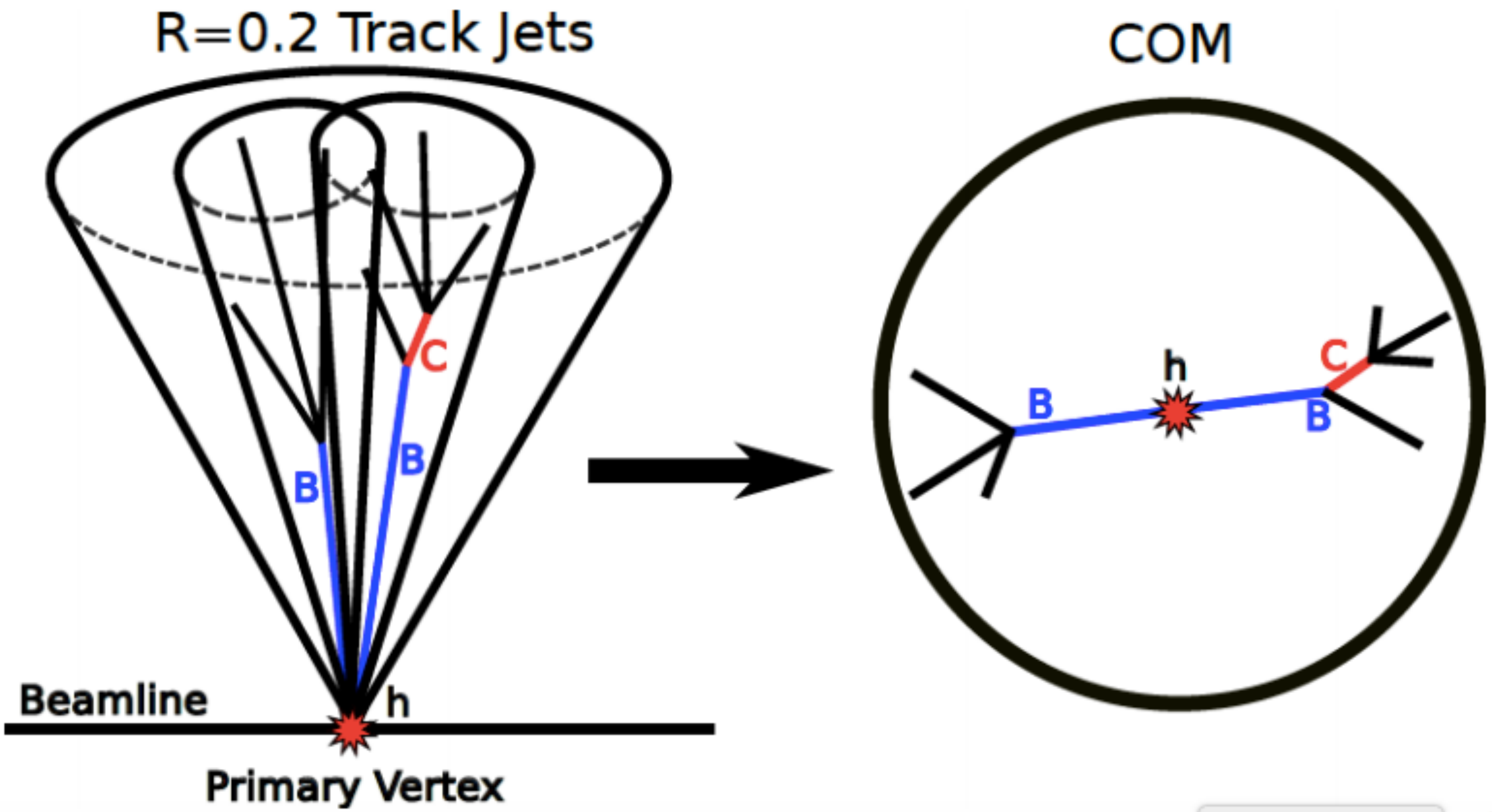




Prospect of future X->H+γ search

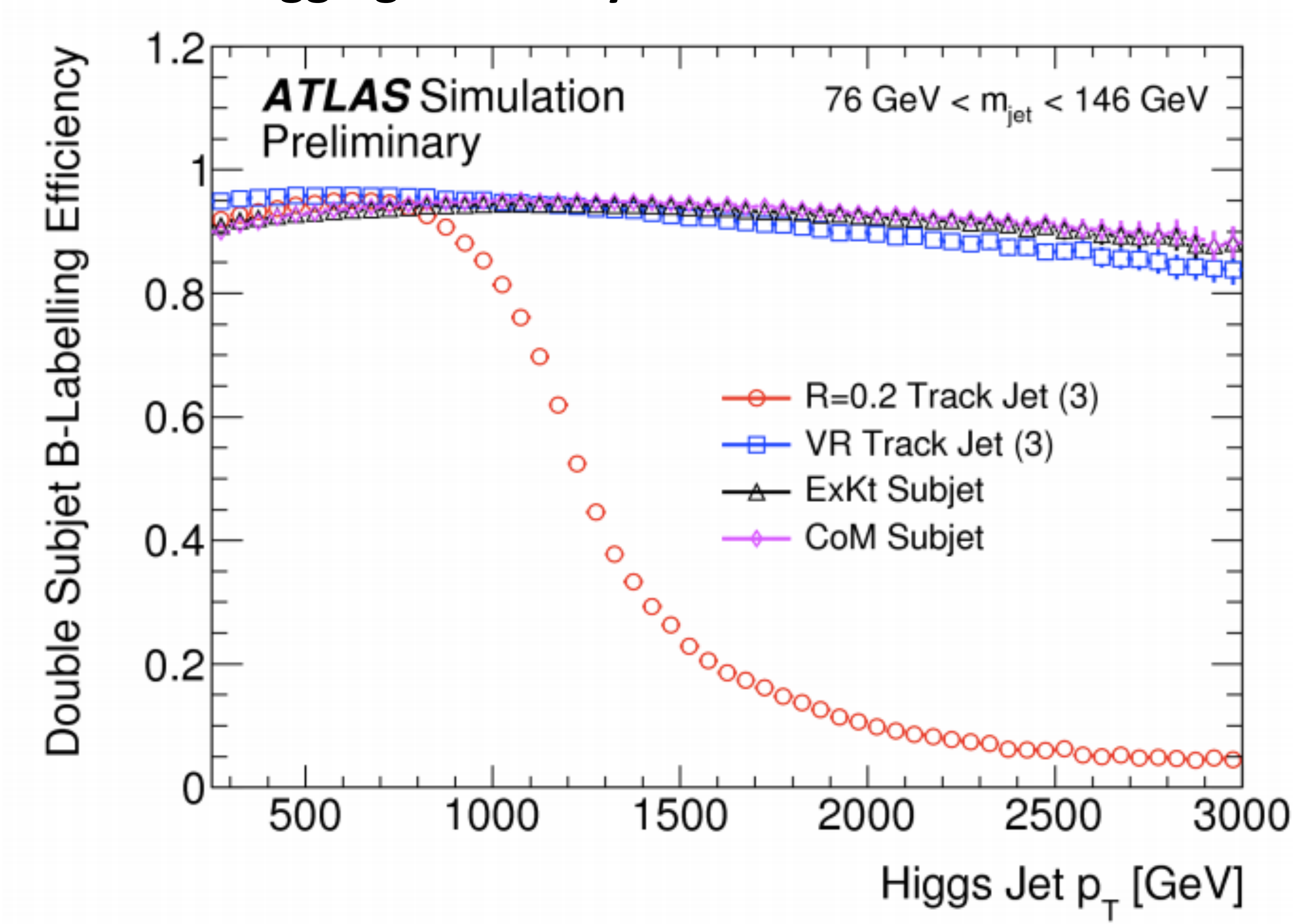
- Development in advanced double b jet tagger

> - Boost to the Higgs jet center of mass frame (COM)
> - Use Higgs jet constitutes to cluster 2 EECambridge subjets
> - Use angular seperation in COM for track-to-subjet association
> - Boost back to the lab frame to apply for b-tagging



Prospect of future X->H+γ search

Expect significant improvement in full run-2 dataset
In double b tagging efficiency



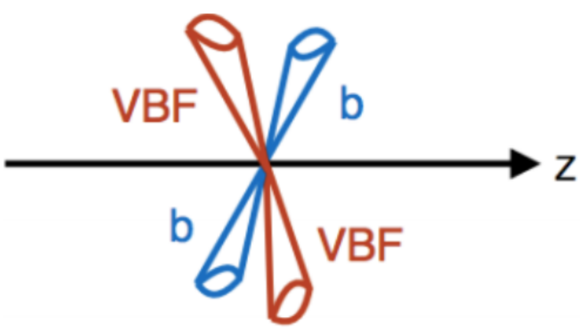
Summary

- First observation of H->bb decay mode by ATLAS and CMS
  - Chinese group made key contribution
- Some major theory systematics need more study in next steps
  - Modelling of W+b jets, Z+jets in high pT region
  - tt+bb backgroud
- Boosted Higgs reconstruction technique in BSM search

Trigger

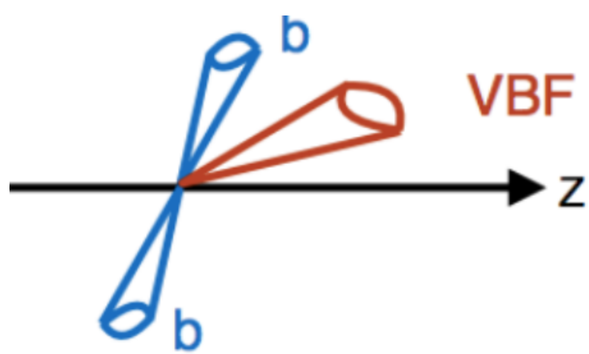
- divided into 3 channels based on triggers:
  - VBF inclusive
    - Two central : 4 central jets with 2 bjet(2b+2j)
    - Four central: 2 central + 1 forward trigger jet (1fj+2b)
  - VBF+photon
    - Photon: photon + 2bjet+2 forward jets (γ+2b+2fj)

L1 trigger: 4 central Jet



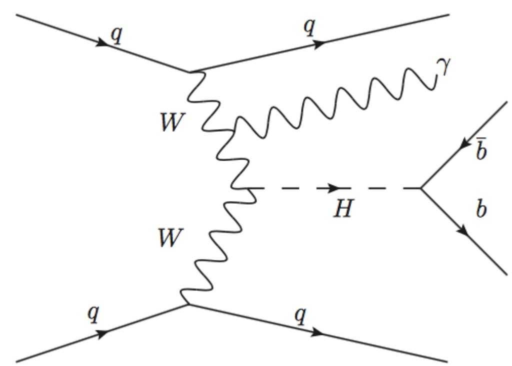
Four central Channel (2b+2j)

L1: 1 forward jet +2 central jets



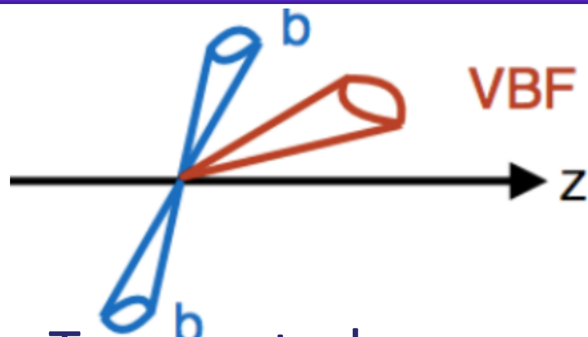
Two central Channel (1fj+2b)

L1: 1 EM object

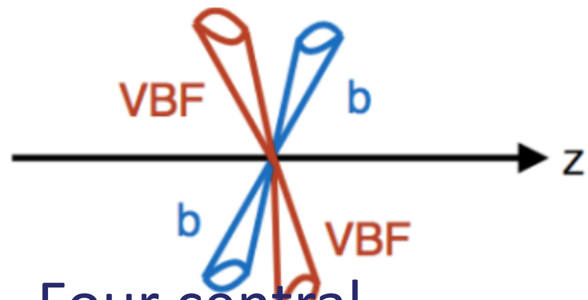


Photon channel γ+2b+2fj

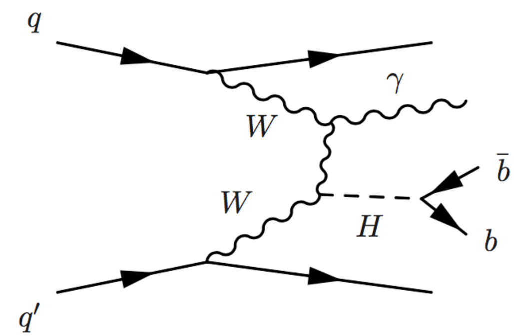
Event Selection



Two central Channel (1fj+2b)



Four central Channel (2b+2j)



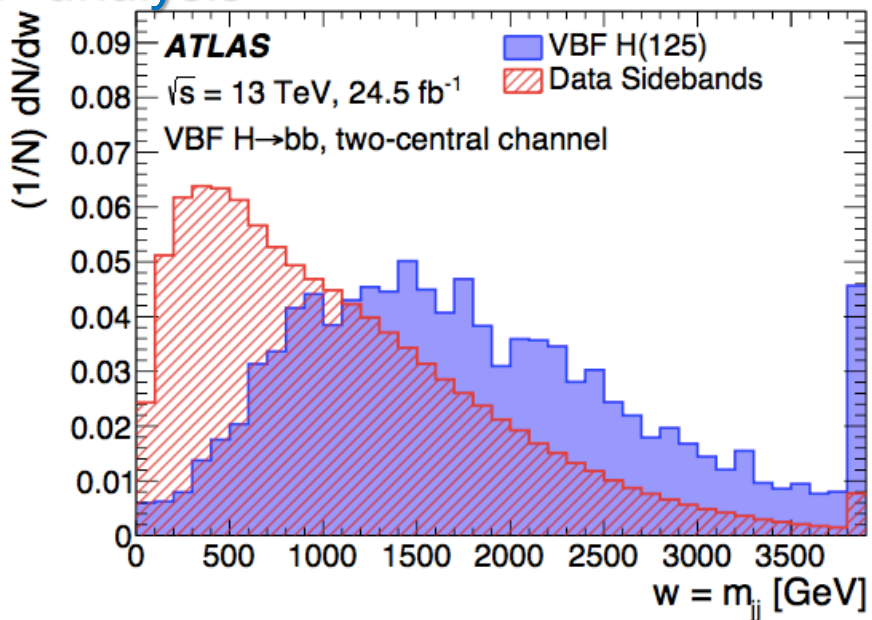
Photon channel γ+2b+2fj

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

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

Boost decision tree analysis

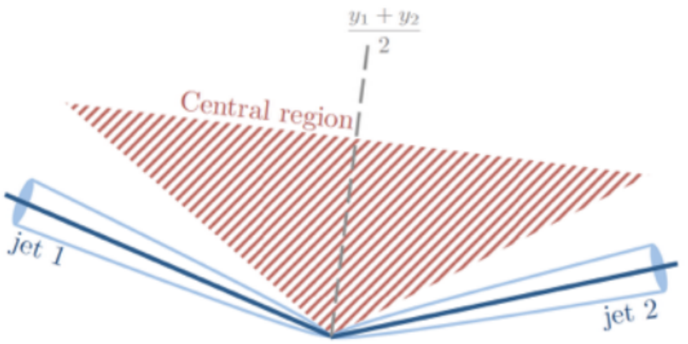
- More than 10 variable used in BDT analysis



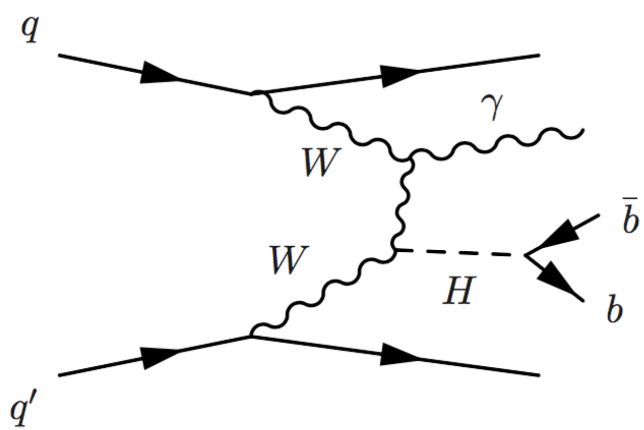
	VBF H(bb) Inclusive	VBF H(bb)+Photon
g/q seperation	Ntrk(j1),Ntrk(j2) minΔR(J1),minΔR(J2)	Ntrk(j1),Ntrk(j2)
VBF jets	p_T(JJ), M(JJ),ΔM(JJ) Max(η(J1), η(J2))	p_T(JJ), M(JJ), Δη(JJ)
Color connection	$p_T^{balance}$ η* (Higgs centrality)	$p_T^{balance}$ Photon Centrality
Angular	cos θ(bb,jj)	ΔR(b1,γ),ΔR(b2,γ),Δϕ(bb,jj),cos θ

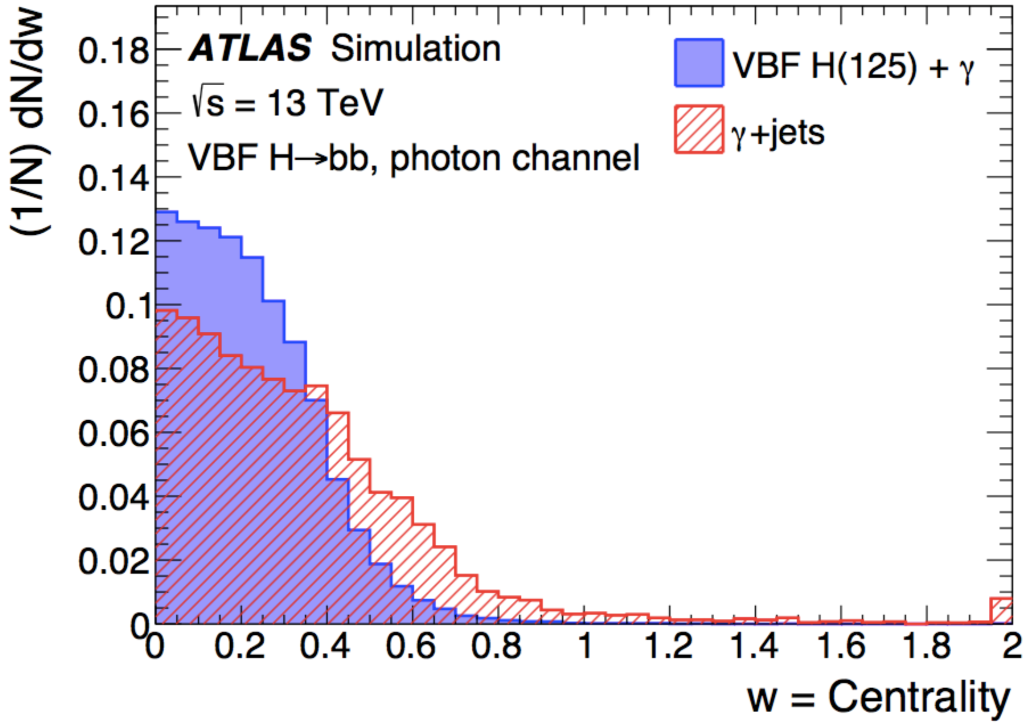
MVA Input variable: photon centrality

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



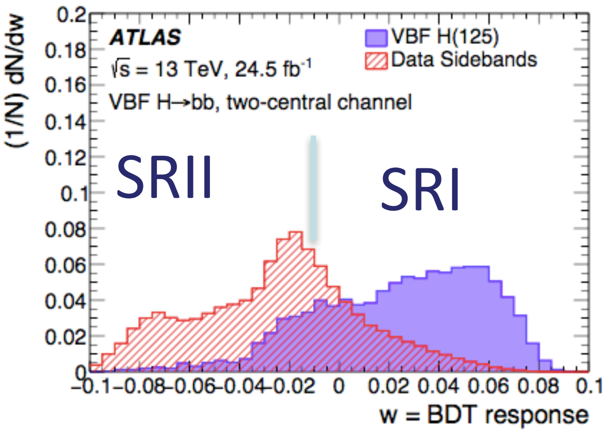
No color connection between VBF jets and b jets in signal



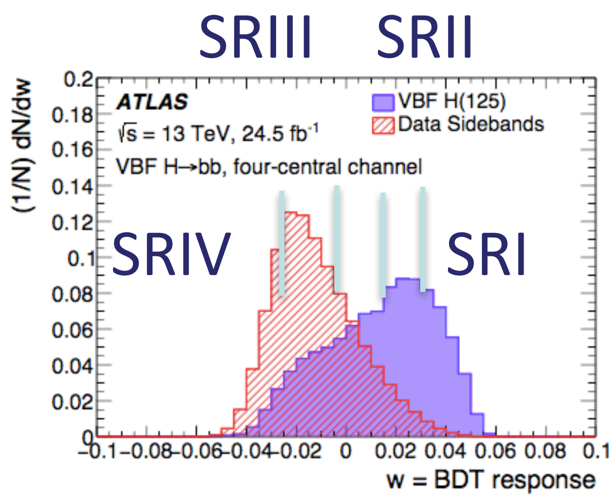


BDT response

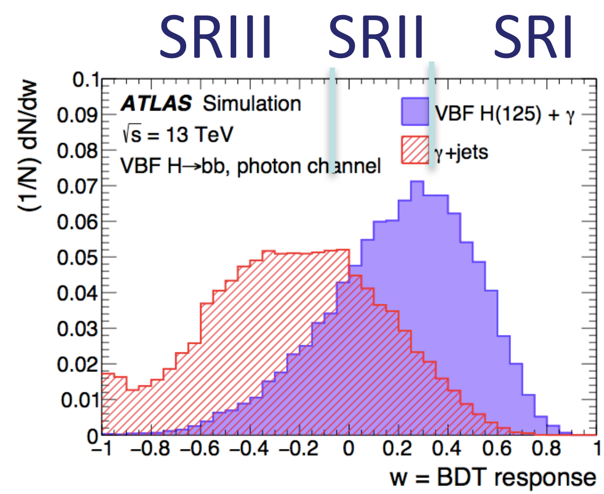
- Divide into 9 categories based on BDT weight
  - Expected Higgs and Z events in 100GeV<m(bb)<140GeV



Two central



Four central

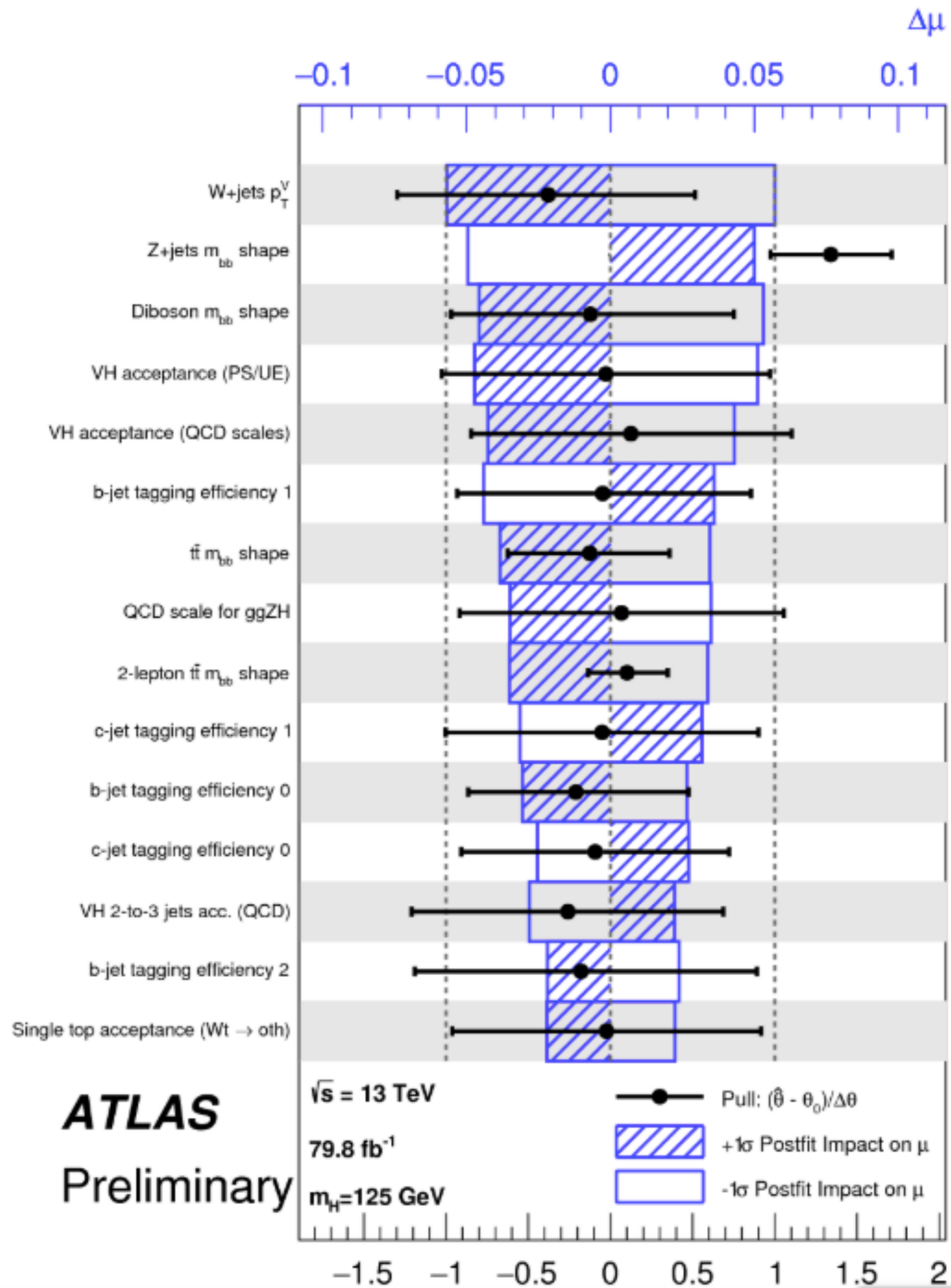


Photon channel

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									
VBF	101.2±2.0	22.2±0.9	51.6±1.1	28.4±0.9	43.1±1.0	41.9±1.1	6.2±0.1	5.5±0.1	2.3±0.1
ggF	23.8±2.6	75.7±6.1	11.3±2.2	13.2±1.5	43.4±3.8	127.0±6.5	0.5±0.2	0.3±0.1	0.8±0.3
VH	0.2±0.2	6.0±1.2	1.2±0.9	0.7±0.3	3.9±0.8	28.9±2.6	<0.1	<0.1	<0.1
ttH	2.0±0.2	14.6±0.7	0.3±0.1	1.0±0.1	5.7±0.3	20.2±0.5	<0.1	<0.1	0.4±0.1
$Z+$jets ($Z\gamma$)	183.1±50.6	515.1±73.4	76.42±14.8	119.4±21.9	385.4±48.5	1224.6±97.9	2.4±0.1	6.9±0.1	13.0±0.1

VH(bb)

- Major systematics :
  - W+jet p_T(W) modelling
  - m_{bb} shape in Z+jets
  - m_{bb} shape in diboson
  - Signal accetance



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