Study of ZH→llbb with the ATLAS detector

Chikuma Kato[1,2], TDLI[1], SJTU[2]

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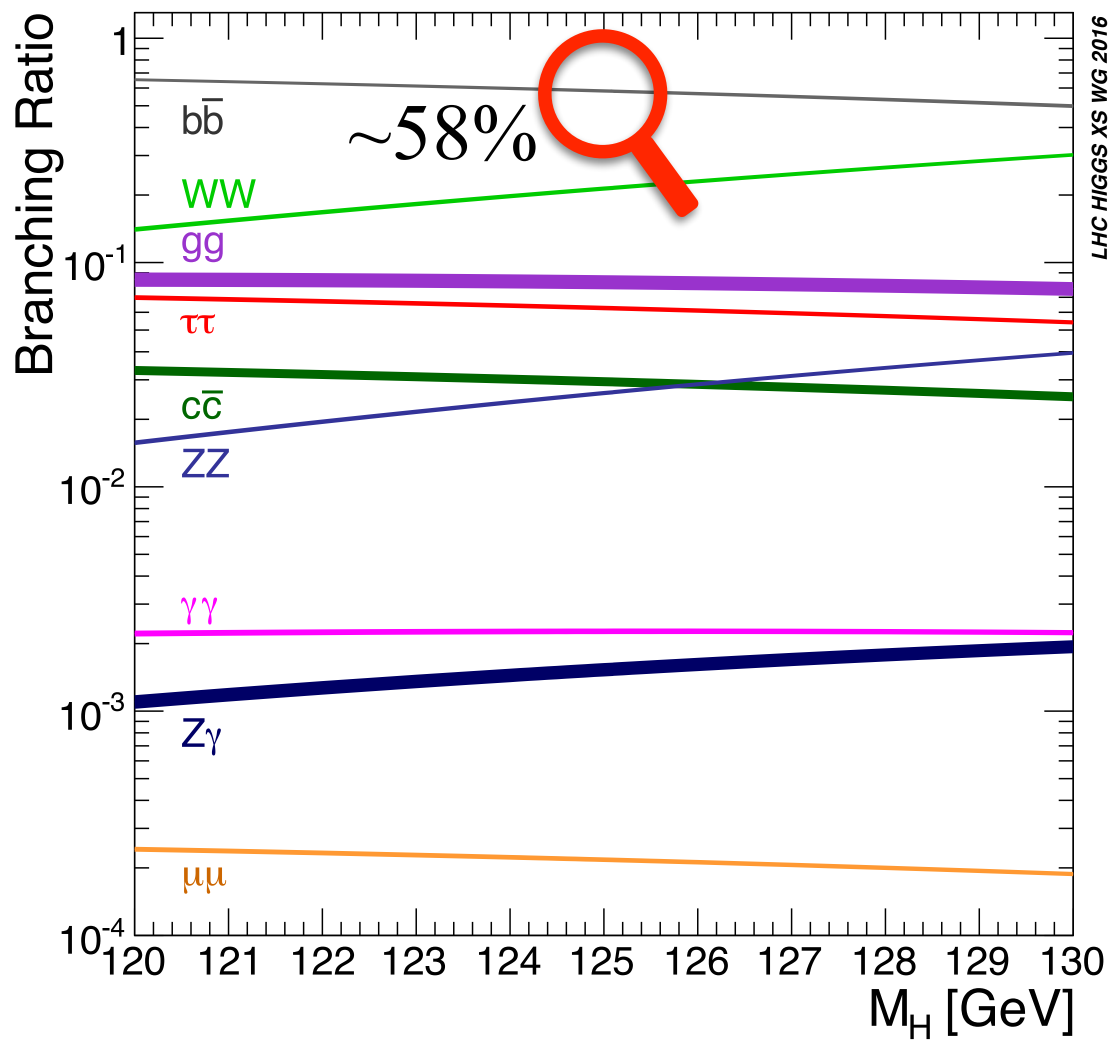
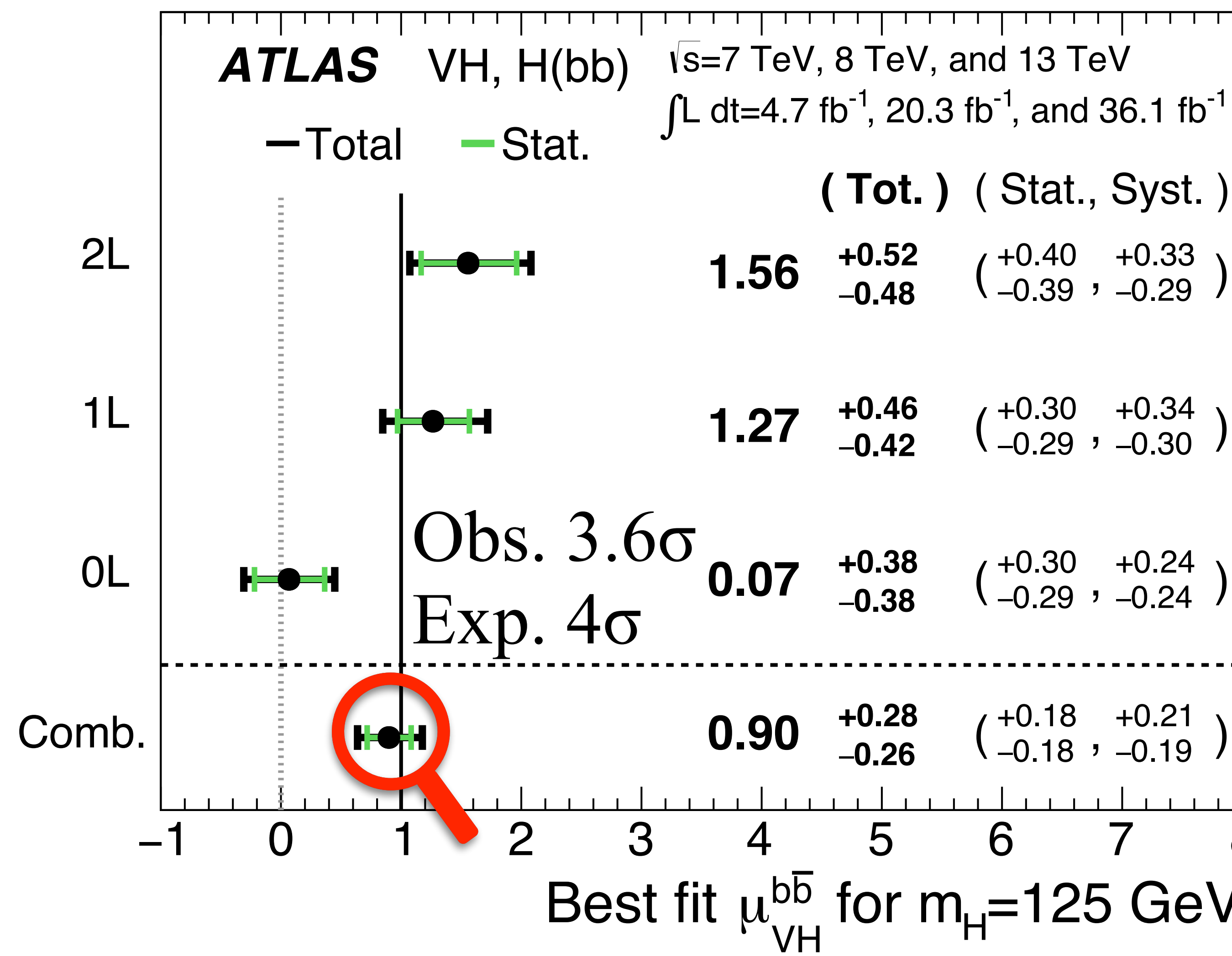
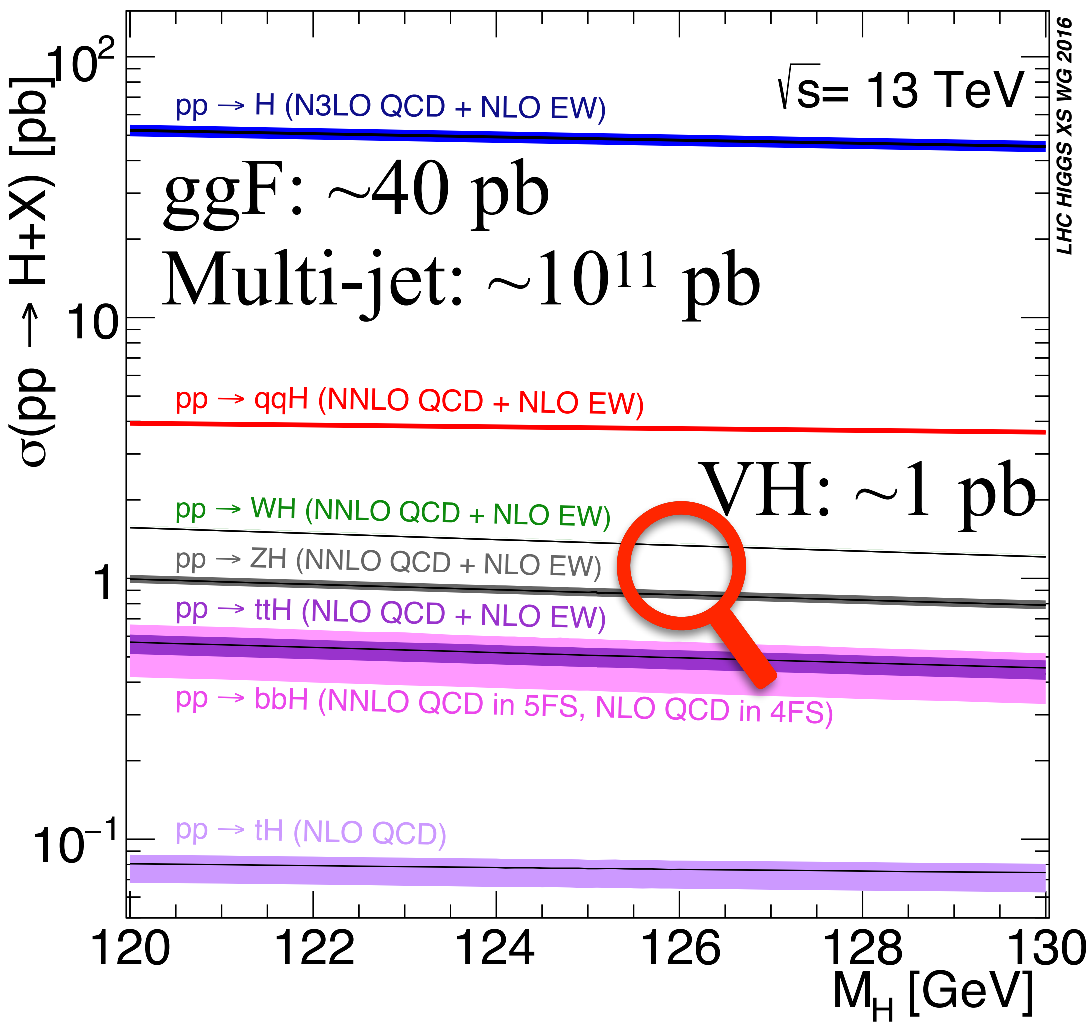
Introduction (1)

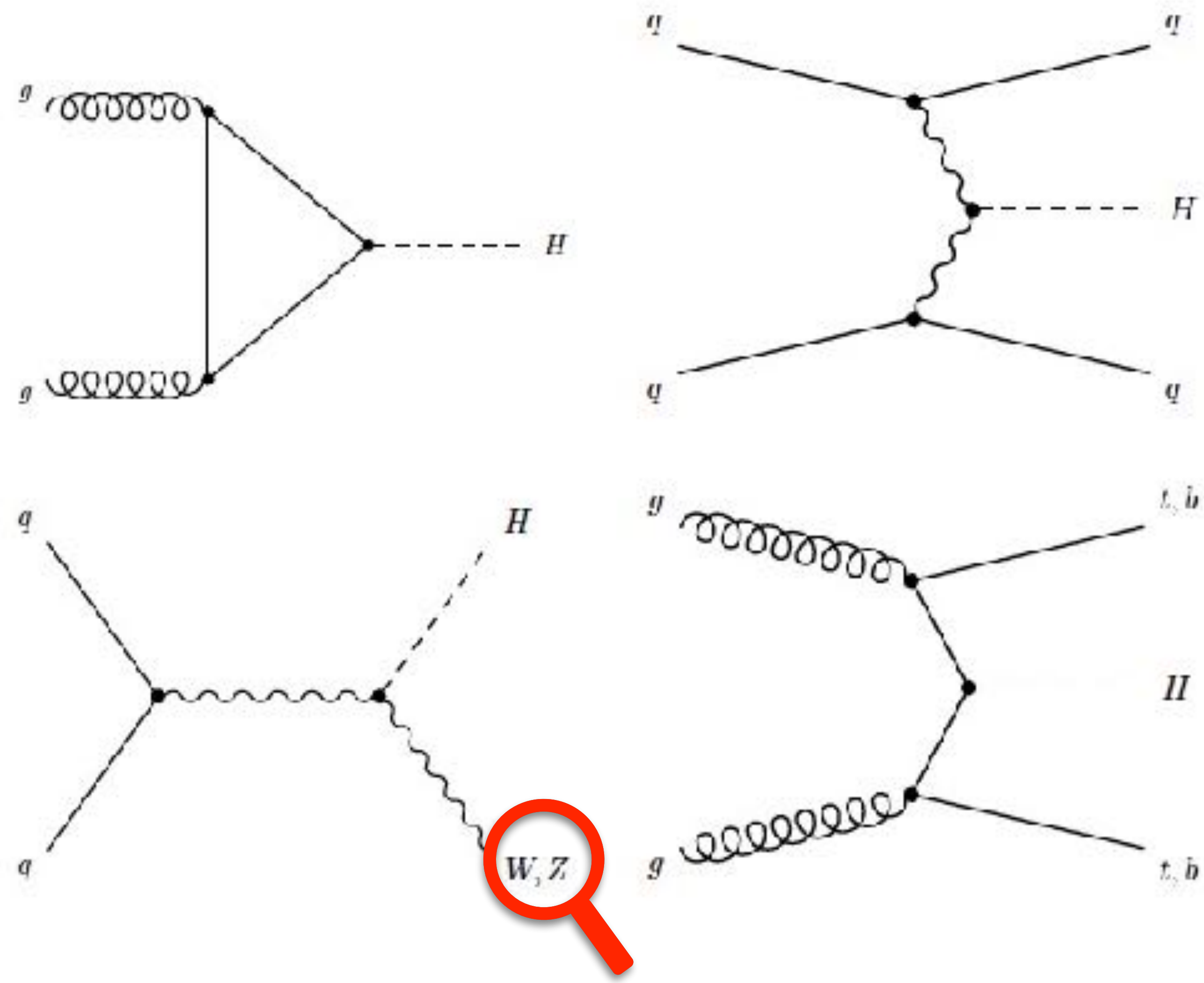




- H→bb is the most dominant decay of the Higgs boson in the Standard Model (SM) [1]
- In 2017, evidence (3σ) for the H→bb was reported by the ATLAS and CMS experiment [2,3]

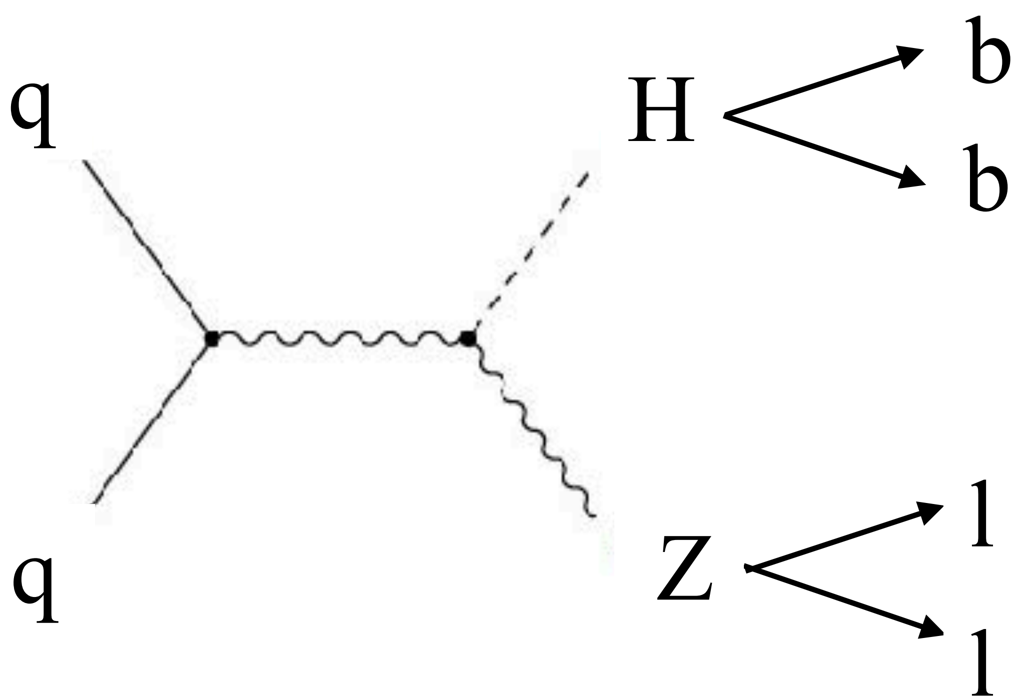
Introduction (2)

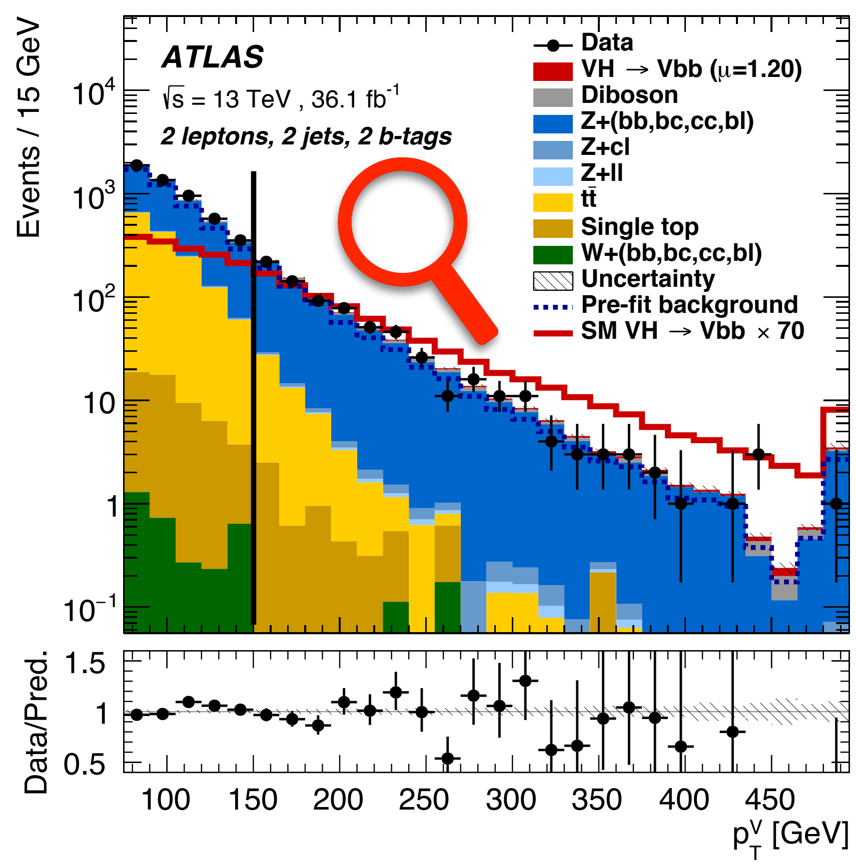




- Vector boson associated production (VH) is the most sensitive channel for the H→bb [4]
- In order to reach observation (5σ), statistical and systematic uncertainties need to be reduced
- Study of ZH→llbb with the ATLAS detector is presented

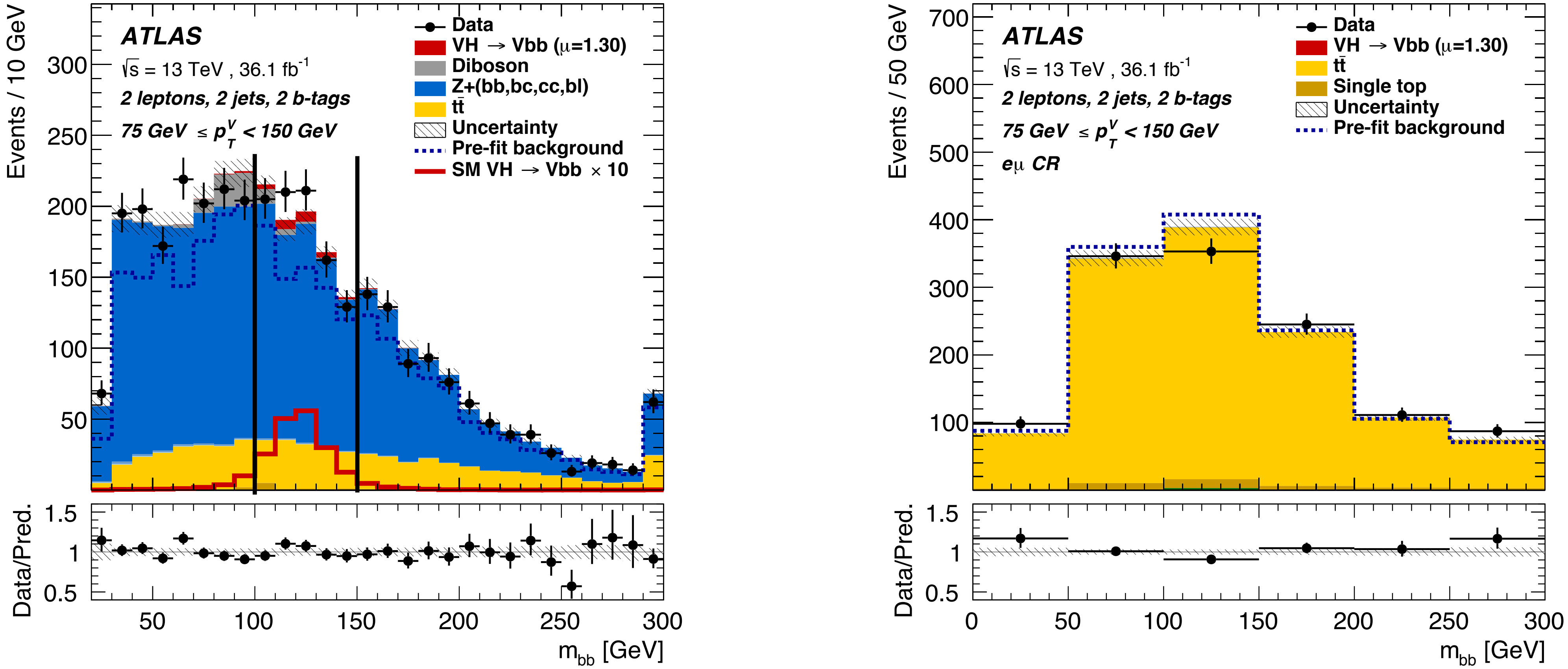
ZH → llbb analysis





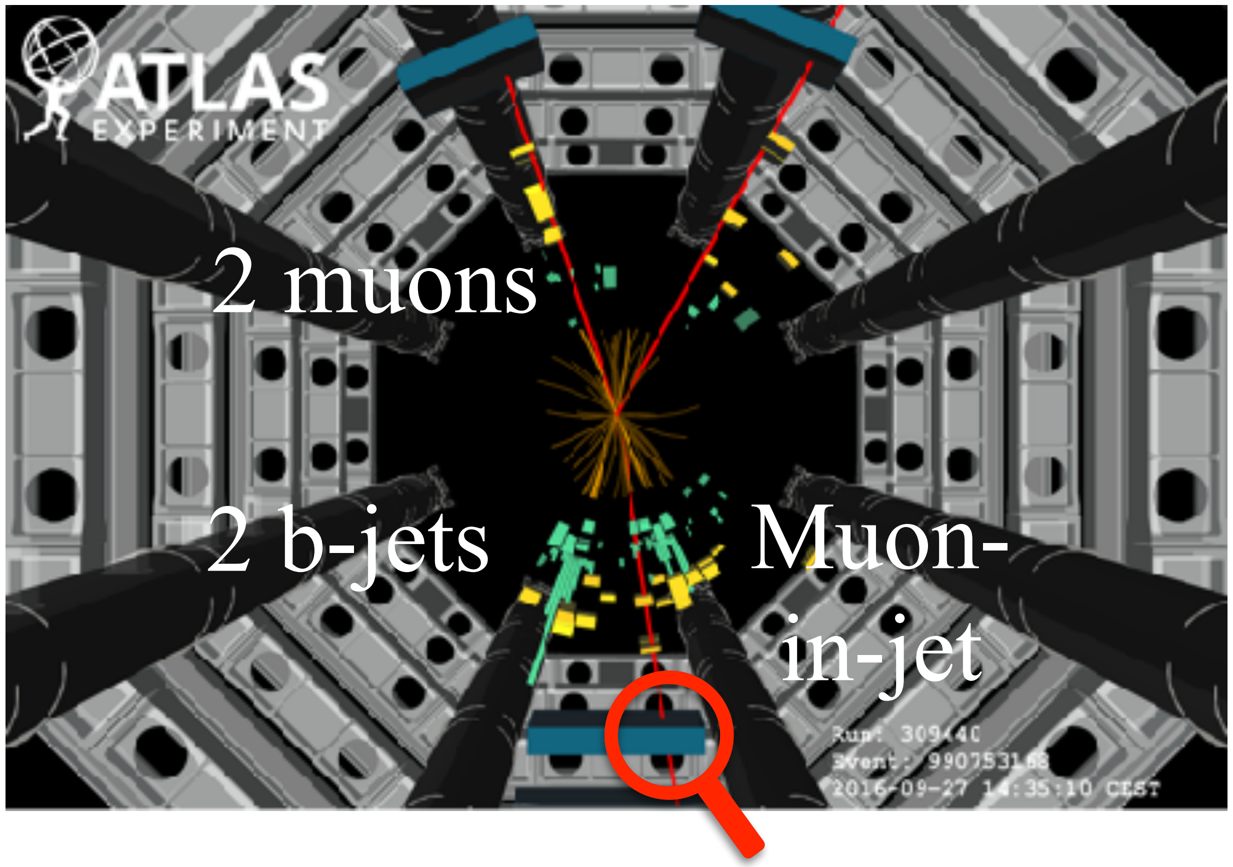
- Event selection: 2 leptons & 2 b-jets
  - m(ll)=81–101 GeV to reduce ttbar and multi-jet
  - b-tag efficiency 70% to reduce Z+jets
- Event categorization: 2 jet, high pT(V) region is sensitive
  - (2 jet, 3≦ jets)*(pT(V)=75–150, 150≦ GeV)
  - Signal regions (SR) and top emu control regions (CR)

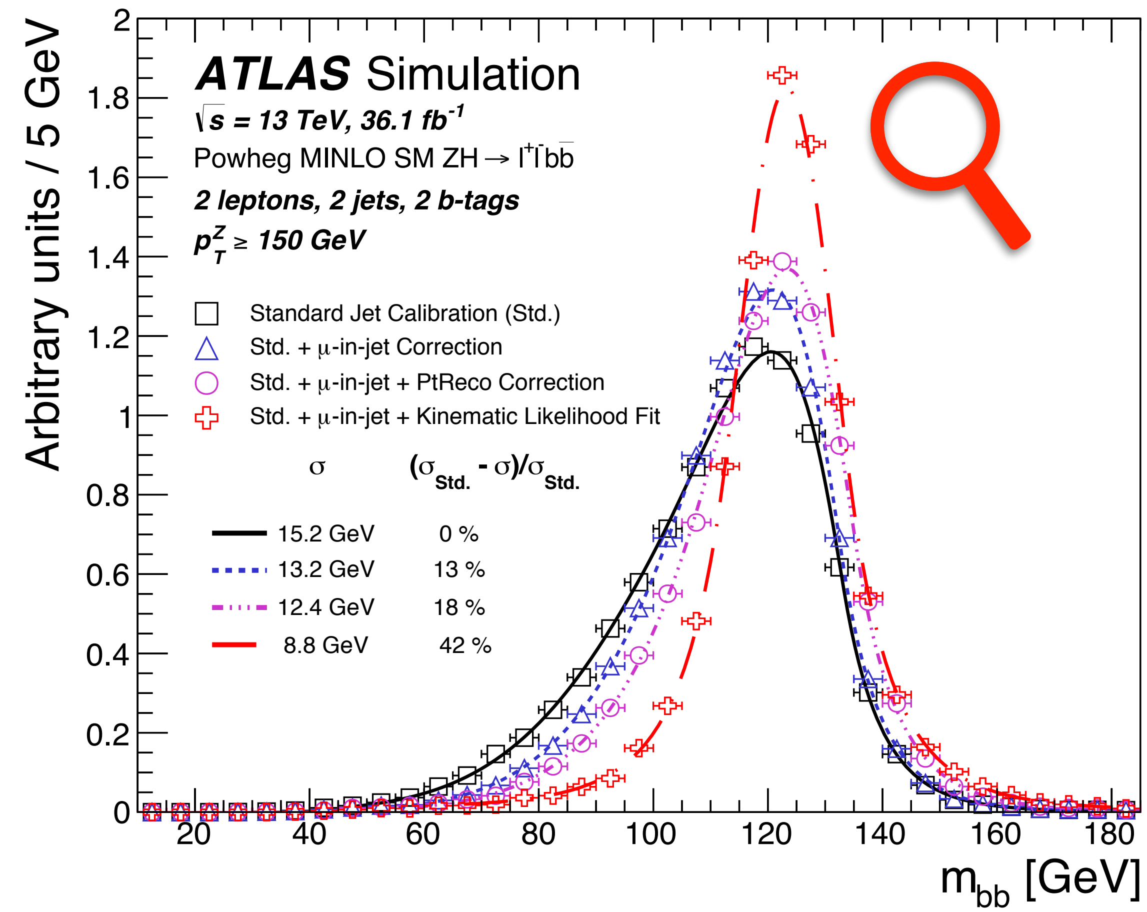
Background estimation



- Main backgrounds are estimated using data and Monte Carlo simulation (MC) in signal depleted regions
  - Z+bb is estimated using m(bb) sideband (left)
  - ttbar is estimated using top emu CR (right)
- Diboson and single-top are estimated using MC
- Multi-jet is estimated using data

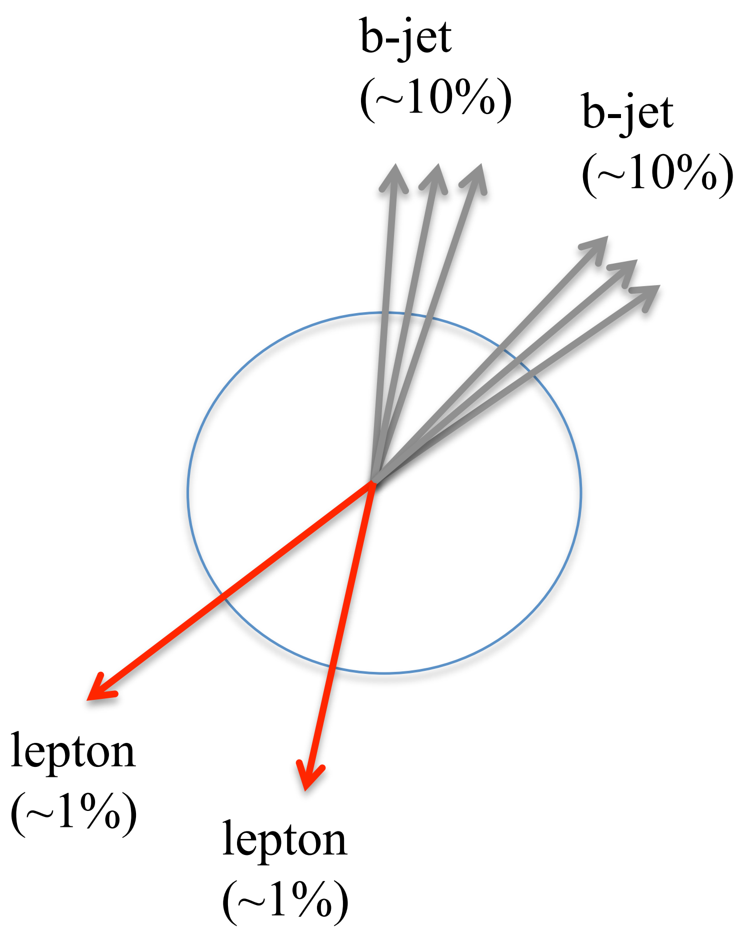
b-jet energy correction





- Standard jet calibration: Not optimized for b-jet → dedicated b-jet energy correction can improve the Higgs mass resolution
- Muon-in-jet correction: Add semileptonic decay muon back to jet after subtracting energy loss in the calorimeter
- PtReco correction: Apply pT dependent correction factor

Kinematic fit:



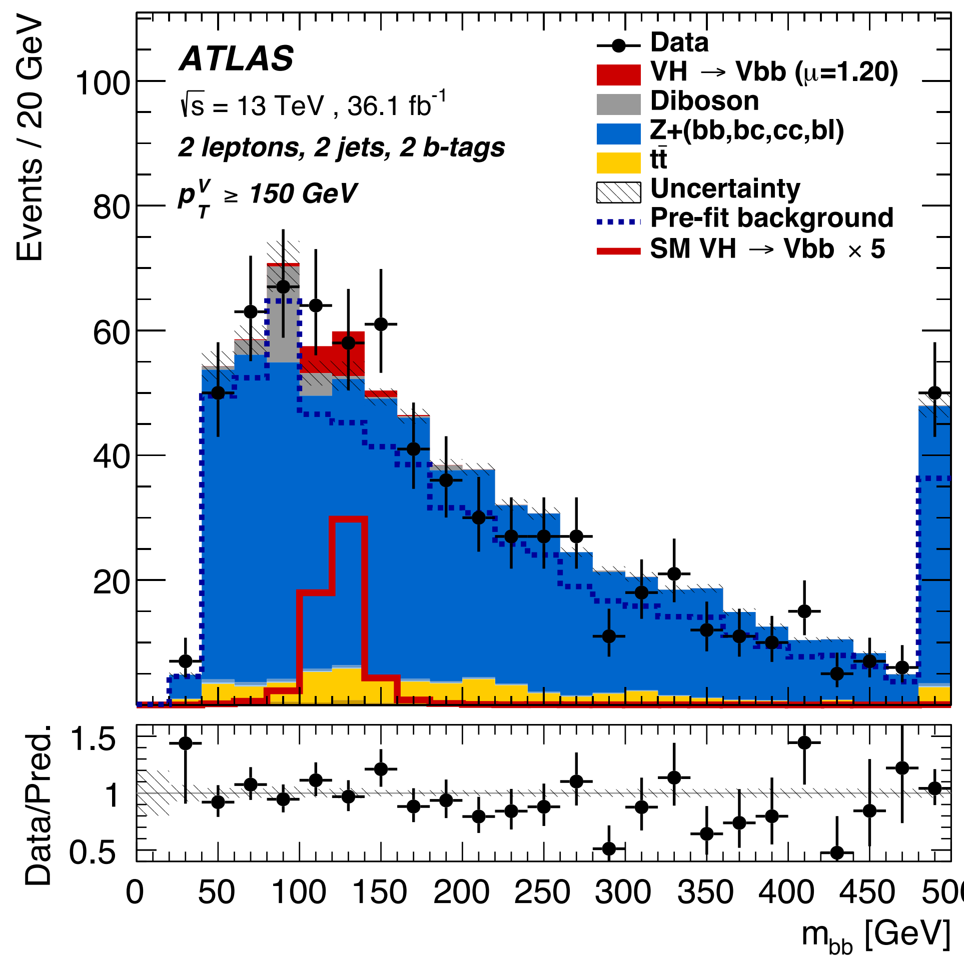
$$-2\ln L = \sum_i \frac{\left(E_i^{obs} - E_i^{fit}\right)^2}{\sigma^2_{E_i}} - 2\ln L_b + \frac{\left(p_X^{Zh}\right)^2}{\sigma^2_{p_X^{Zh}}} + \frac{\left(p_Y^{Zh}\right)^2}{\sigma^2_{p_Y^{Zh}}} + 2\ln\left\{(m_{ll}^2 - m_Z^2)^2 + m_Z^2\Gamma_Z^2\right\}$$

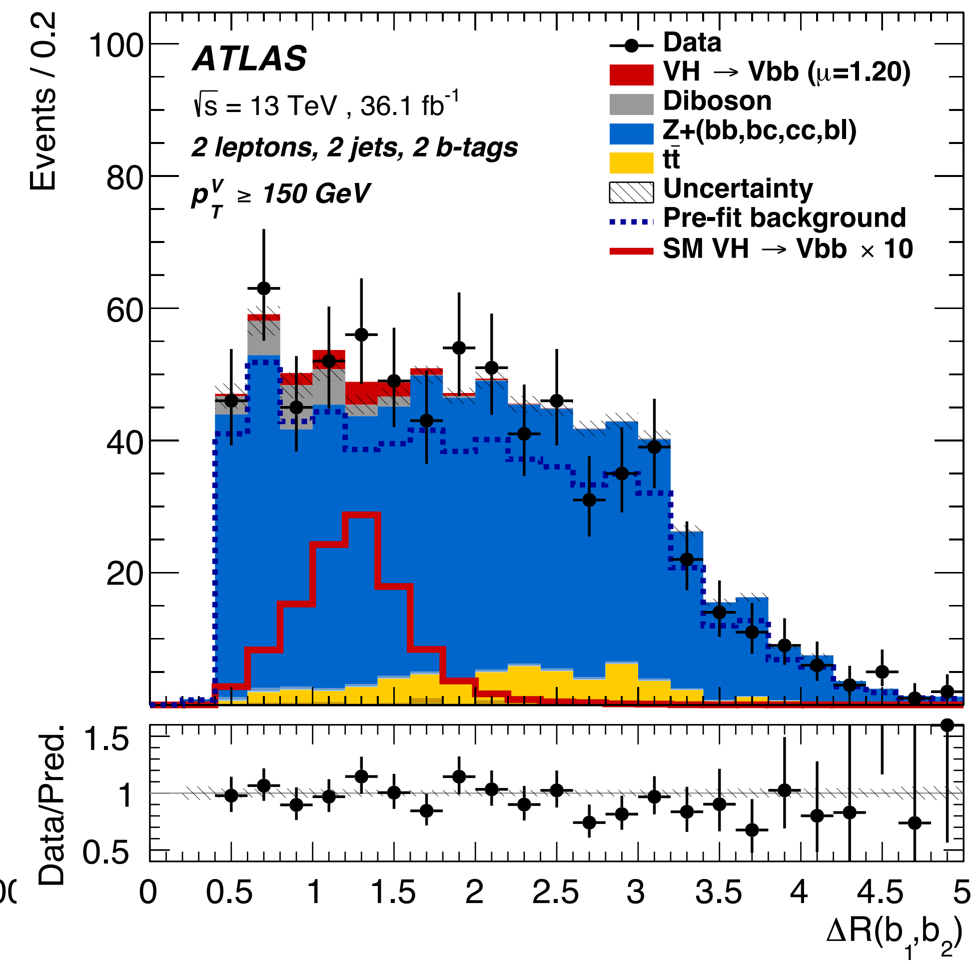
- $-2\ln L$: Maximize likelihood and get fit value
- $E(e)$, p_T^{μ} : Gaussian (resolution)
- p_T^{b} : Transfer Functions
- p_X^{Zh}, p_Y^{Zh} : Gaussian (simulation)
- m_{ll} : Breit-Wigner

- Constrains llbb system to be balanced in the transverse plane and improve b-jet energy correction
- ~40% gain in the Higgs mass resolution

Multivariate analysis

	Variables
2 jet	m_{bb}
	dR(b,b)
	$d\phi$(V,bb)
	$d\eta$(V,bb)
	p_T^V
	p_T^{b1}
	p_T^{b2}
	MET
	m_{ll}
$\geq$ 3 jet	p_T^{j3}
	m_{bbj}





- Multivariate discriminant using Boosted Decision Tree (BDT_{VH}) separates signal and background efficiently
- ~20% gain in sensitivity applying looser event selection compared to cut-based analysis

Systematic uncertainties

- Experimental uncertainties are summarized as 61 Nuisance Parameters in the statistical analysis:
  - b-tag efficiency: 2, 10, 30% for b, c, light jet
  - Jet energy scale: 4.5% for pT=20 GeV, 2% for pT=2 TeV
- Signal and background modeling uncertainties are estimated comparing MC samples, generators, scale variations, parton shower, etc.
  - Normalization of main backgrounds are floated

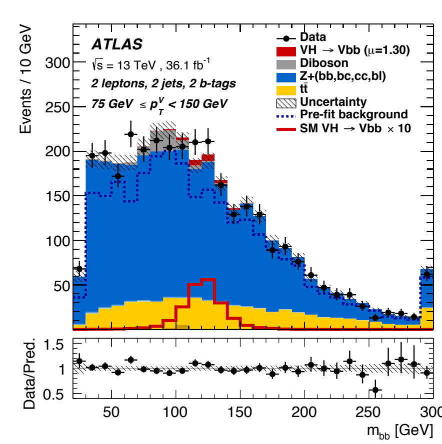
Source of uncertainty		σ_μ
Total		0.39
Statistical		0.24
Systematic		0.31
Experimental uncertainties		
Jets		0.03
$E_{\mathrm{T}}^{\mathrm{miss}}$		0.03
Leptons		0.01
b-tagging	b-jets	0.09
	c-jets	0.04
	light jets	0.04
	extrapolation	0.01
Pile-up		0.01
Luminosity		0.04
Theoretical and modelling uncertainties		
Signal		0.17
Floating normalisations		0.07
Z + jets		0.07
W + jets		0.07
$t\bar{t}$		0.07
Single top quark		0.08
Diboson		0.02
Multijet		0.02
MC statistical		0.13

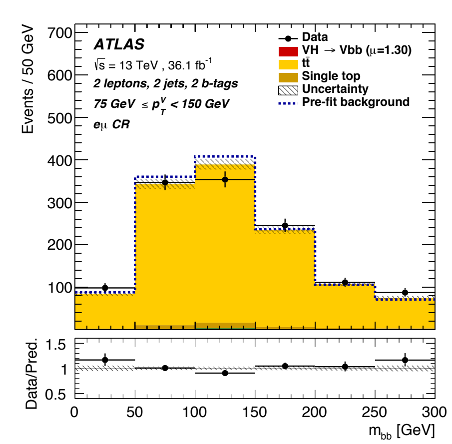
Statistical analysis

- Maximum likelihood fit is performed to estimate background, test background only hypothesis, and extract signal strength (μ)
- The likelihood is described as a product of Poisson probability of each bin in the BDT_{VH} or m(bb) distributions
- Systematic uncertainties are also included as Nuisance Parameters (θ) and constrained by normal or log normal distributions

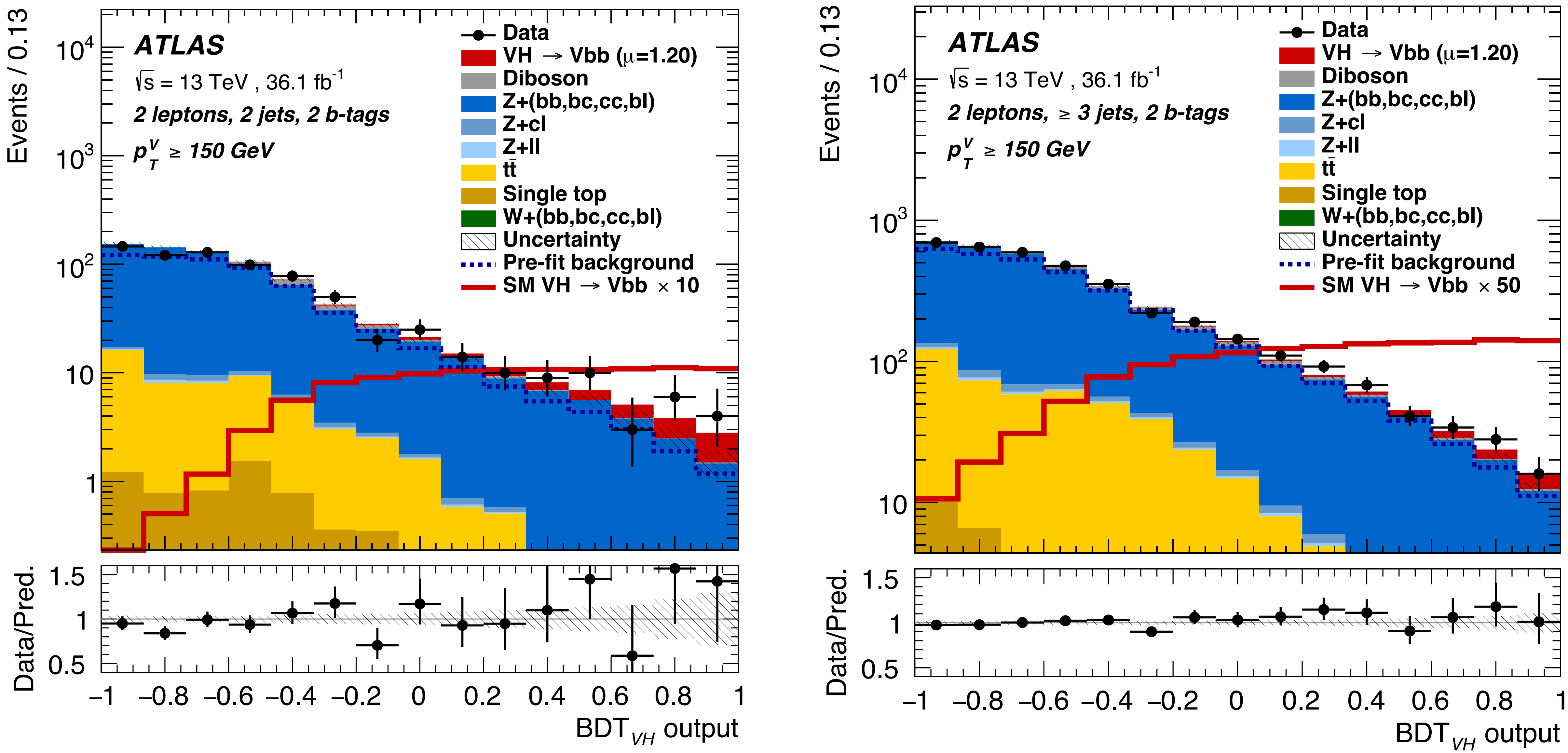
$$L(\mu, \boldsymbol{\theta}) = \prod_{i \in bins} P(n_i | \mu s_i(\boldsymbol{\theta}) + b_i(\boldsymbol{\theta})) \prod_{j \in \boldsymbol{\theta}} G(\theta_j)$$

- The floating normalization of main backgrounds are constrained by data in low BDT_{VH}, m(bb) sideband, and top emu CR:
  - Z+bb (2 jet): 1.28 ± 0.13
  - Z+bb (≥ 3 jet): 1.15 ± 0.10
  - ttbar (2 jet): 0.98 ± 0.11
  - tt (≥ 3 jet): 1.03 ± 0.07



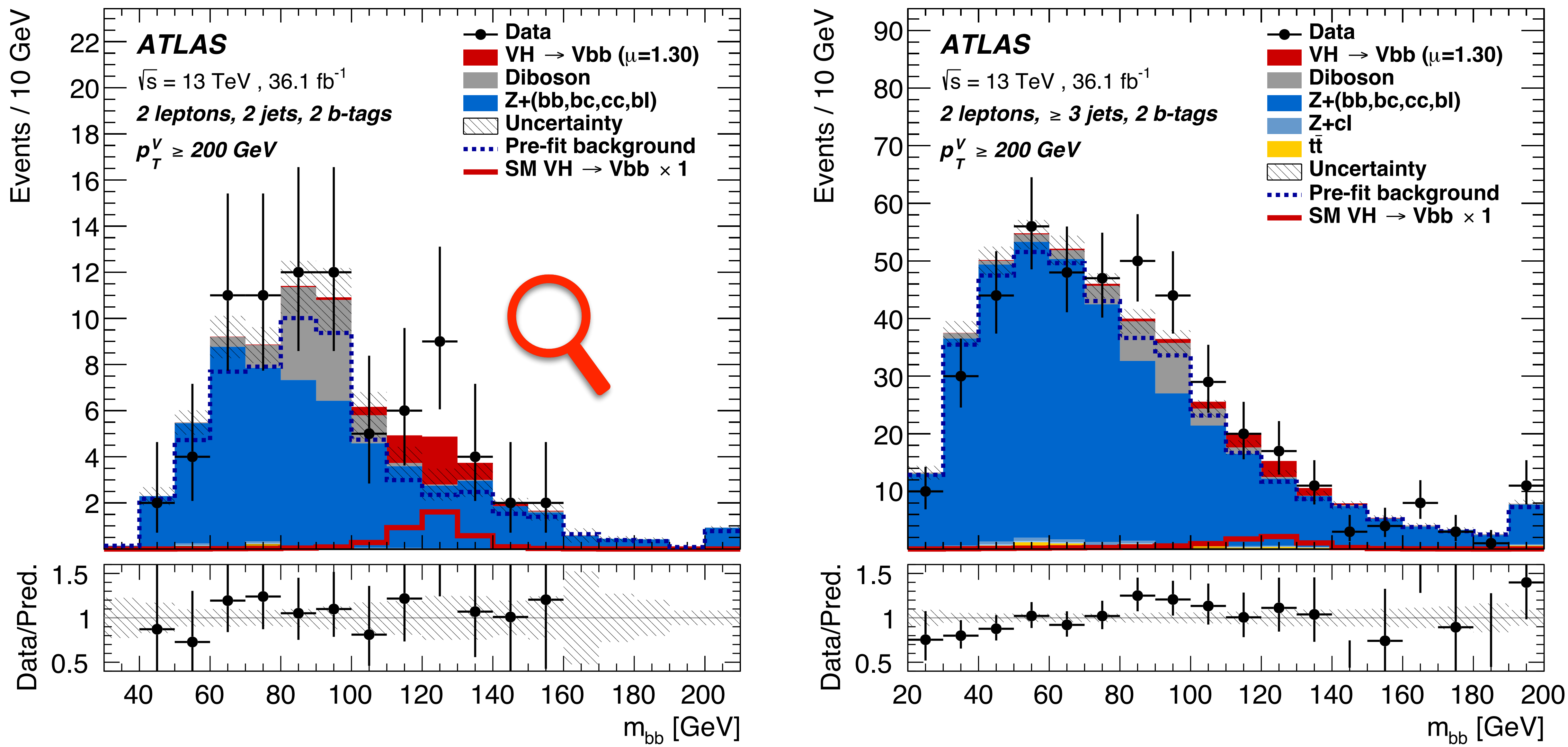


Results of multivariate analysis



- Observed significance: 3.6σ
- Expected significance: 1.9σ
- Signal strength: $\mu = 1.90\ ^{+0.51}_{-0.49}\ \text{(stat.)}\ ^{+0.59}_{-0.42}\ \text{(syst.)}$

Results of cut-based analysis



- Signal strength: $\mu = 2.20\ ^{+0.61}_{-0.59}\ \text{(stat.)}\ ^{+0.70}_{-0.49}\ \text{(syst.)}$

Summary and future plans

- Study of ZH→llbb with the ATLAS detector is presented
- b-jet energy correction: ~40% gain in the Higgs mass resolution
- Results of multivariate analysis
  - Observed significance: 3.6σ
  - Expected significance: 1.9σ
  - Signal strength: $\mu = 1.90\ ^{+0.51}_{-0.49}\ \mathrm{(stat.)}\ ^{+0.59}_{-0.42}\ \mathrm{(syst.)}$
- Results of cut-based analysis
  - Signal strength: $\mu = 2.20\ ^{+0.61}_{-0.59}\ \mathrm{(stat.)}\ ^{+0.70}_{-0.49}\ \mathrm{(syst.)}$
- Future plans
  - 130 fb^{-1} at the end of Run2 in 2018
  - Kinematic fit using soft track information
  - Data driven background estimation

Thank you!

References

[1] LHC Higgs Cross Section Working Group, 2016, https://cds.cern.ch/record/2227475

[2] ATLAS Collaboration, 2017, JHEP 12 (2017) 024

[3] CMS Collaboration, 2017, PLB 780 (2018) 501

[4] ATLAS and CMS Collaborations, 2016. JHEP 08 (2016) 045

Luminosity extrapolation