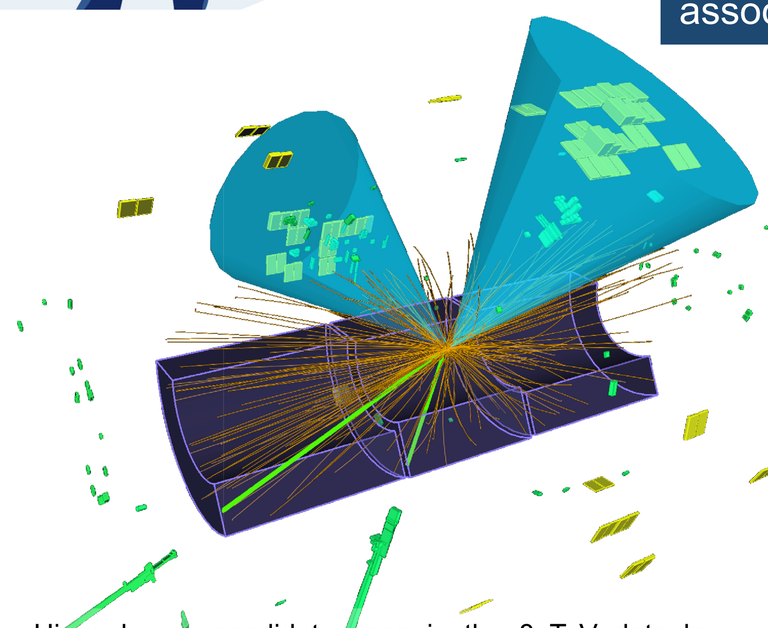
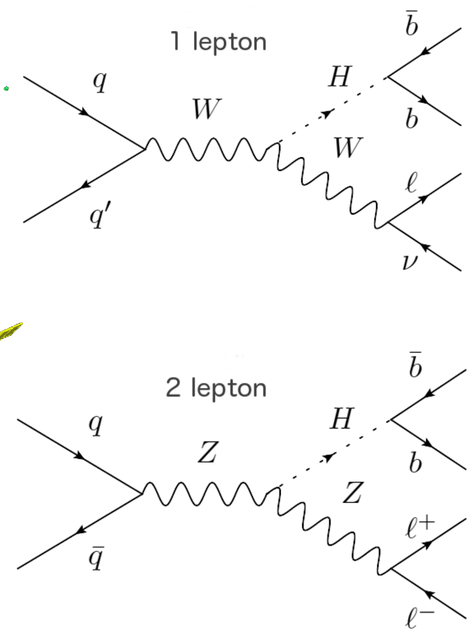
An ATLAS study of VH→Vb$\bar{b}$ for the High Luminosity LHC

A key outstanding observation is the decay of the Higgs boson to b-quarks, motivating a study into the prospects of this channel in future LHC runs. Despite the largest predicted branching ratio of 57%, H→b$\bar{b}$ suffers from an overwhelming background. Studying Higgs candidates which are produced in association with a vector boson V, with V→ $\ell\ell$, $\ell\nu$ increases the signal to background ratio by 10^6.



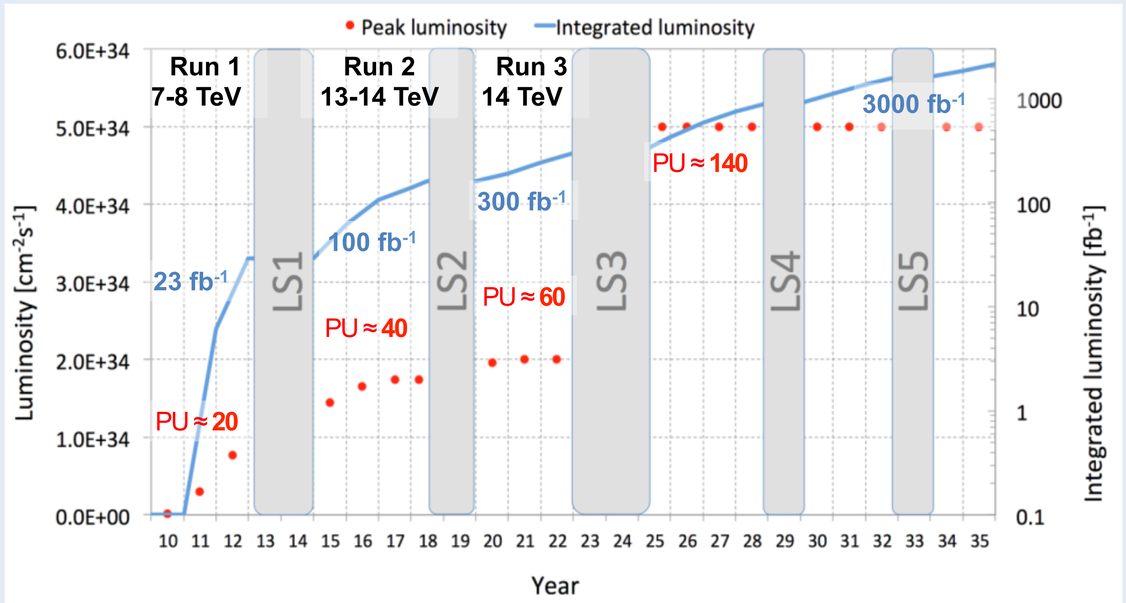


Higgs boson candidate seen in the 8 TeV data by ATLAS, with two b-jets (cones) and two electrons (lines). Current Run 1 analysis results on H→b$\bar{b}$ yield an observed (expected) signal significance of 1.4σ (2.6σ) and a ratio of measured cross section to Standard Model prediction μ= 0.5±0.4 [1].

A significant measurement in this channel requires a vastly larger data-set than the 20.3 fb^{-1} obtained in Run1, which will be collected in the upcoming 14 TeV LHC runs.

Future LHC runs and pile-up

Higher luminosity comes hand-in-hand with higher **event pile-up (PU)**, introducing more pile-up jets, overall degrading particle ID. Planed detector upgrades, primarily to the inner detector are assumed which mitigate expected pile-up effects, preserving and even improving on current detector performance.



VH with H→b$\bar{b}$ simulation strategy for the HL-LHC

Estimate the significance and μ=σ/σ_{SM} for ZH→$\ell\ell$ b$\bar{b}$ and WH→$\ell\nu$ b$\bar{b}$ using:

- Standard Model (SM) m_H=125 GeV, √s =14 TeV proton-proton collisions
- ∫ L dt = 300 fb^{-1} with a pile-up (PU) of 60 and ∫ L dt = 3000 fb^{-1} with PU=140
- Upgraded ATLAS detector: upgraded tracker with Run 1 calorimeter and muon system
- efficiency functions were obtained from fully simulated samples for different PU scenarios including an upgraded detector
- particle level data and smear for inefficiencies linked to pileup and resolution effects,
- As a validation, published cut-based 8 TeV results[2] were reproduced. Same cuts and object selection were used for 14 TeV except for jet p_T thresholds.
- Impact of improvements in analysis technique made since the 2013 publication[2] in form of MVA analysis and continuous b-tagging[1] were propagated as scale factors to results

[1] *Search for the bb decay of the SM Higgs boson in associated (W/Z)H production with the ATLAS detector*, arXiv: 1409.6212

[2] *Search for the bb decay of the Standard Model Higgs boson in associated W/ZH production with the ATLAS detector.* ATLAS-CONF-2013-079

HL-LHC Detector Response

Efficiency functions applied for loose and tight **leptons** and to mimic **lepton trigger.** Uniform 97% muon efficiency used

Anti-k_T, R = 0.4 particle level **jets** + smeared resolution and reconstruction efficiency, track-jet confirmation efficiency applied

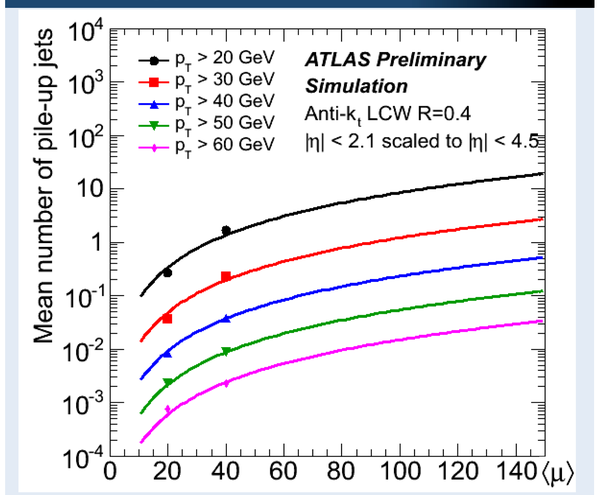
Flavour–tagging with truth hadrons. MV1 parameterization using 70% **b-tag** efficiency working point

Missing Transverse Energy (**MET**) calculated as momentum vector sum of stable truth particles in detector acceptance,

Overlap removal between jets and leptons and jets **faking electrons** included, as well as track and calorimeter lepton **isolation**

Performance assumptions for an upgraded ATLAS detector at HL LHC, ATL-PHYS-PUB-2013-009

Pile-up jets



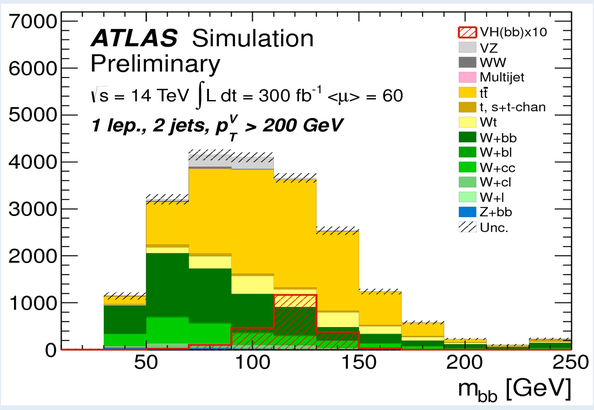
The increase in **pile-up jets** requires higher jet p_T thresholds to be applied compared to the 8TeV analysis. $p_T^{lead\ jet}$, $p_T^{sub\text{-}lead\ jet}$ and $p_T^{extra\ jet}$ cuts were raised from 45, 20 and 20 GeV to 60, 40 and 30 GeV, thus maintaining a 1% fake rate.

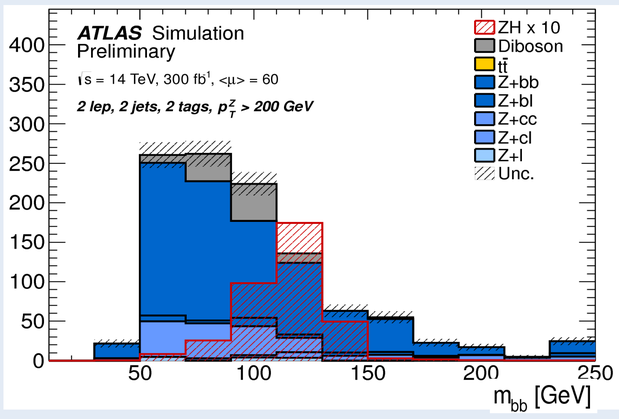
Search for VH with H→b$\bar{b}$

Optimal sensitivity is achieved by classifying events depending on the number of leptons, transverse momentum of the gauge boson candidate and jet multiplicity.

		One-lepton			Two-lepton	
Leptons		1 tight lepton+0 loose lepton			2 loose leptons	
Jets		2 b-tags with $\lvert\eta\rvert < 2.5$; p_T(leading jet) > 60 GeV, p_T(sub-leading jet) > 40 GeV; ≤ 1 extra jet (p_T > 30 GeV and $\lvert\eta\rvert < 2.5$)				
	p_T^V(GeV)	0 – 90	90 – 120	120 – 160	160 – 200	> 200
All channels	$\Delta R(b,b)$	0.7 – 3.4	0.7 – 3.0	0.7 – 2.3	0.7 – 1.8	< 1.4

Signal and all background samples were generated at 14 TeV, except for Multi-jet which was obtained from PDF rescaling of 8TeV samples. NLO EW correction is applied to qq generated WH and ZH signal sample.





m_{bb} distribution for both 1-lepton (left) and 2-lepton (right) for the 300 fb^{-1} estimate of signal and background in the most sensitive selection category, i.e. two jets and p_T > 200 GeV. The dashed band corresponds to the statistical uncertainty.

WH channel suffers from lower MET resolution and decreased S/B at 14 TeV, due to pile-up jets and enhanced t$\bar{t}$ cross section.

Significance		300 fb^{-1}	3000 fb^{-1}
ZH	Stat only	4.6 σ	11.3 σ
	w/theory+sys	3.5 σ	8.4 σ
WH	Stat only	5.5 σ	15.4 σ
	w/theory+sys	1.8 σ	2.7 σ
ZH +WH	Stat only	7.1σ	19.1 σ
	w/theory+sys	3.9 σ	8.8 σ

Significance and signal strength are obtained from a binned Log-likelihood fit using a reduced set of systematic uncertainties.

Main Experimental uncertainties

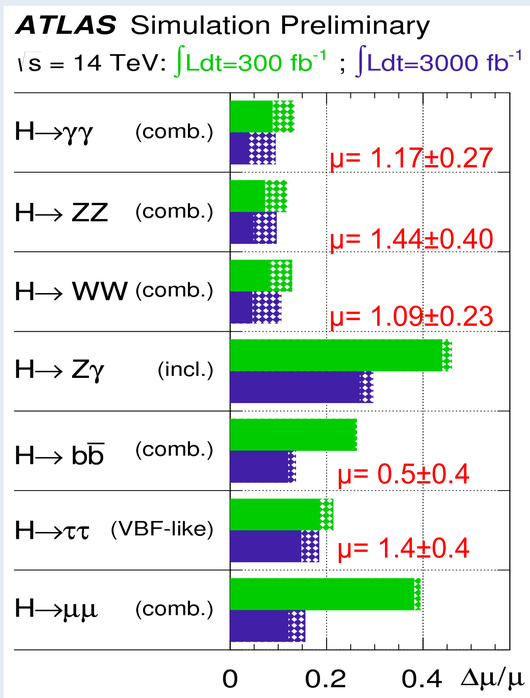
- **Jet Energy Scale**: uniform 10%
- **Background normalization:** as measured in 8TeV analysis, up to 30% for W,Z+jets
- **b/c-tagging:** taken from 8TeV analysis, typically 3%, 8% for jet p_T >200 GeV
- **MET:** parameterized, minimum of 5GeV
- **Luminosity normalization**: 2.8%

Theory uncertainties (14TeV YellowReport)

- **QCD Scale**: 50% ggVH, 1.5% qqVH
- **PDF**: 17% ggVH, 3.8% qqVH
- **NLO EW correction** to signal : 2%

A study of Standard Model Higgs boson production in the decay mode H -> bb in association with a W or Z boson for High Luminosity LHC Running, ATL-PHYS-PUB-2014-011

Higgs prospects summary



Relative signal strength error Δμ/μ shown for all ATLAS SM Higgs prospects studies.[3] The hashed areas indicate current theory errors. Added in red are current (9Dec 2014) 8 TeV values[4] of μ.

[3] *Projections for measurements of Higgs boson signal strengths and coupling parameters with the ATLAS detector at the HL-LHC*, ATL-PHYS-PUB-2014-016

[4] *https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/HIGGS/* (23Dec 2014)

Expect first observation of H→b$\bar{b}$ in future LHC runs !

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ATLAS EXPERIMENT