SM Higgs in Fermion Decay modes in ATLAS

Nicolas Morange

THE UNIVERSITY OF IOWA

SUSY 2014 conference, Manchester

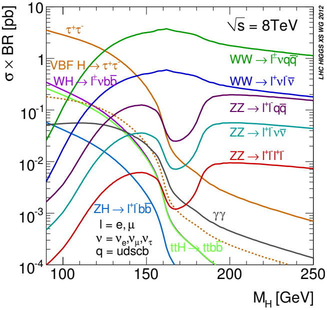
July 22, 2014

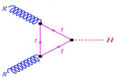
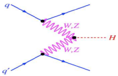
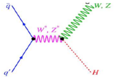
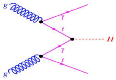
SM Higgs in fermion decays

Higgs discovery made with boson decays

Fermion decays : crucial item for Higgs coupling studies

- Universality of Higgs coupling
- Linear dependence on fermion mass
- Constraint to total Higgs width
- ⇒ Explore as many channels as possible
- ⇒ But low S/B channels

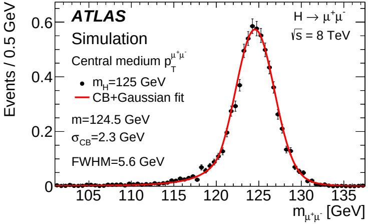


	Gluon fusion	VBF	Associated VH	Associated $t\bar{t}H$
				
$H \to \mu^+\mu^-$ (0.022%)	CERN-PH-EP-2014-131, submitted to Physics Letters B			
$H \to \tau^+\tau^-$ (6.3%)	ATLAS-CONF-2013-108		–	–
$H \to b\bar{b}$ (58%)	–	–	ATLAS-CONF-2013-079	ATLAS-CONF-2014-011

$H \to \mu^+\mu^-$: Analysis

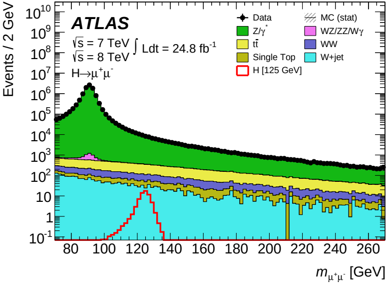
A very clean signature

- Two high-p_T(25/15 GeV), isolated, opposite-sign muons
- No E_T^{miss}(80 GeV)
- ⇒ Acceptance × efficiency ∼ 55%
- ⇒ Excellent resolution: 2–3 GeV

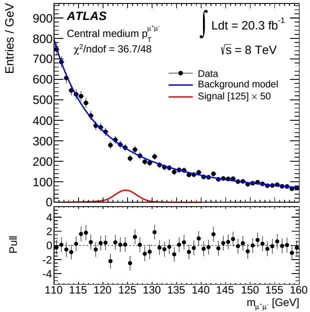


Backgrounds

- Drell-Yan: 96%
- $t\bar{t}$: 3%
- Smooth background shape



$H \rightarrow \mu^+\mu^-$: Results

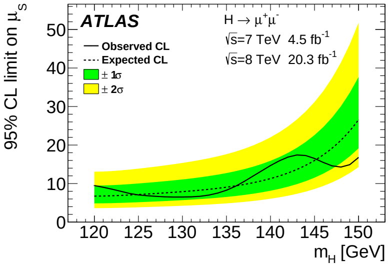


Statistical analysis setup

- Analytical description of background and signal shapes
- Analysis divided in categories of different $S/\sqrt{B}$
  - VBF category with jets
  - Categories with $|\eta^\mu|$ and $p_T^{\mu\mu}$

Results

- Observed (expected) 95% CLs limit at 125.5 GeV: 7.0 (7.2)
- Uncertainty: mostly statistics
- Main systematics: theory ~15% (QCD scales, PDF, Branching ratio)
- Experimental systematics: subleading ~ 4%



Analysis divided into 3 channels

$\tau_{lep}\tau_{lep}$ (BR: 12%)

- 2 opposite-sign e/μ
- τ_{had} veto
- Drell-Yan veto $m_{\tau\tau}^{vis}$
- $E_T^{miss} > 20(40)$ GeV

$\tau_{lep}\tau_{had}$ (BR: 46%)

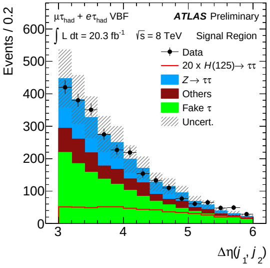
- 1 e/μ + 1 opposite-sign τ_{had}
- $m_T^{\ell,E_T^{miss}}$ cut against W+jets

$\tau_{had}\tau_{had}$ (BR: 42%)

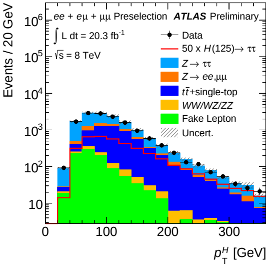
- 2 opposite-sign high-p_T τ_{had} (35/25 GeV)
- e/μ veto
- ΔR / $\Delta\eta$ kinematic cuts
- Alignment of E_T^{miss} with τ_{had}s

Further selections

- b-jet veto
- VBF category
  - 2 well-separated ($|\Delta\eta| > 2$) high-p_T (40, 30 GeV) jets
- Boosted category
  - $p_T^H > 100$ GeV



VBF category



Boosted category

Use of boosted decision trees

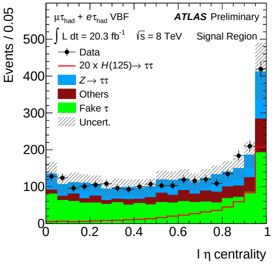
- Trained in each channel and category
- 6 to 9 kinematic variables

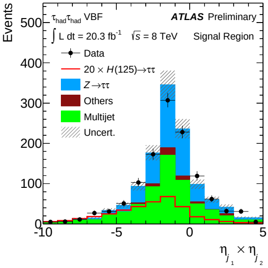
Choice of variables

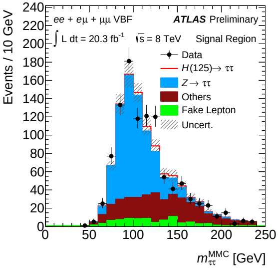
- H resonance: $m_{\tau\tau}^{\text{MMC}}$, $\Delta R(\tau\tau)$
- VBF-specific: $m(j_1, j_2)$, $|\Delta\eta(j_1, j_2)|$
- Boosted-specific: p_{T} of objects, $E_{\text{T}}^{\text{miss}}$ alignment

$m_{\tau\tau}^{\text{MMC}}$

- Mass obtained by solving for missing neutrinos
- Most discriminant variable







$H \rightarrow \tau^+\tau^-$: Background estimation

Most backgrounds are estimated from data or are normalized in dedicated control regions

Main $Z \rightarrow \tau\tau$ background

- Estimated from $Z \rightarrow \mu\mu$ events in data with τ embedding

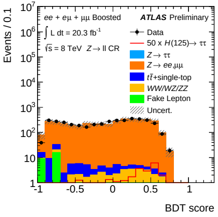
$t\bar{t}$, single top

- Normalized using control region with tagged jets

Events with fake τ

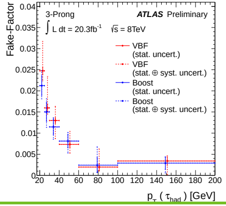
$\tau_{lep}\tau_{lep}$

- Invert isolation of one of the leptons
- Normalize with $p_T^{\ell 2}$



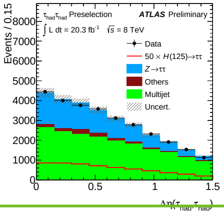
$\tau_{lep}\tau_{had}$

- Fake factors in control regions for gluon jets and quark jets
- Applied in region with loosened τ-ID



$\tau_{had}\tau_{had}$

- Use region with not-opposite-sign τ
- Simultaneous fit of multijet and $Z \rightarrow \tau\tau$ on $\Delta\eta(\tau,\tau)$



$H \rightarrow \tau^+\tau^-$: Systematics

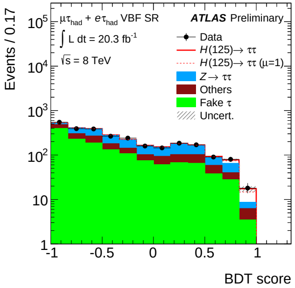
The University of Iowa

ATLAS

Backgrounds

- Normalizations left mostly free in the profile likelihood fit
- Add control regions in the fit to estimate the rates
- Shape systematics from varying control regions

⇒ Main source of systematics

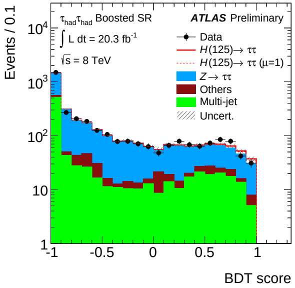


Experimental systematics

- Jet energy scale: significant impact on VBF topology
- τ identification efficiency and τ energy scale

Theory systematics

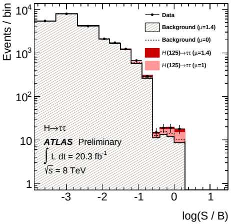
- Modelling of p_T^H
- QCD scales, PDF

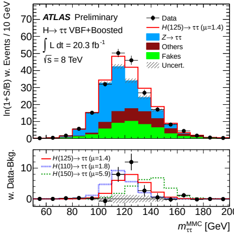


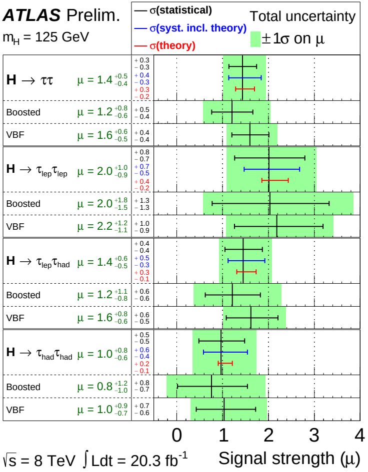
$H \to \tau^+\tau^-$: Results

Direct evidence of Higgs decay to fermions

- Significance: 4.1σ at 125 GeV
  - 3.2σ expected
- Signal strength $\mu = 1.5^{+0.5}_{-0.4}$
  - Results compatible between channels
- $m_{\tau\tau}^{MMC}$ compatible with mass of 125 GeV







$t\bar{t}H \rightarrow b\bar{b}$: presentation

A complex final state

- 2 channels: semi-leptonic / dileptonic $t\bar{t}$ decays
- High jet multiplicity
- High b-jets multiplicity
- Main irreducible background $t\bar{t}+b\bar{b}$ is poorly known

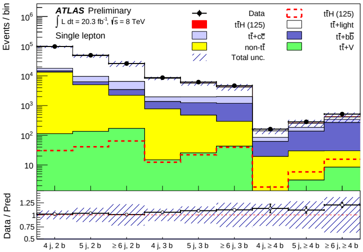
Analysis categorized in number of jets and b-tags

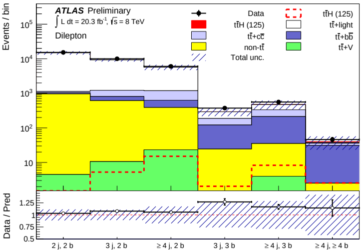
Selection single-lepton

- 1 high-p_T (25 GeV) isolated lepton
- At least 4 jets $p_T > 25$ GeV
- At least 2 of them b-tagged (70% efficiency)

Selection dilepton

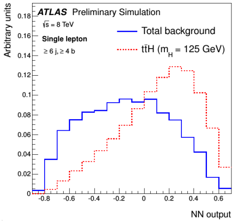
- 2 high-p_T (25 GeV, 15 GeV) isolated leptons
- Z mass veto (ee, $\mu\mu$), H_T cut ($e\mu$)
- At least 2 jets $p_T > 25$ GeV
- At least 2 of them b-tagged





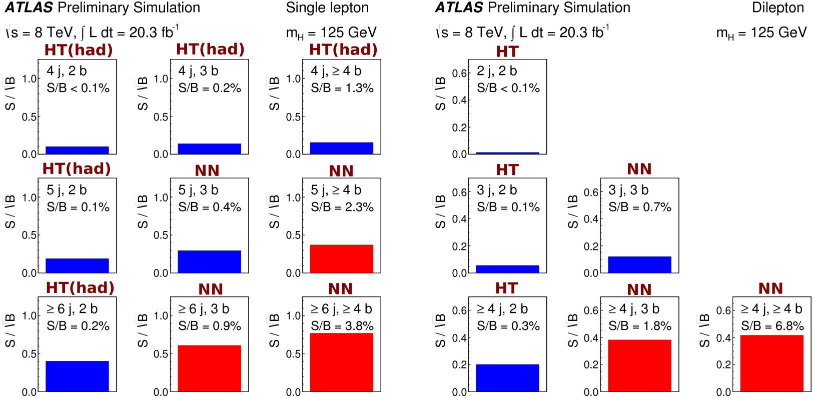
Neural Network in Signal regions

- 10 kinematic variables per region
- Trained in each region



H_T (scalar sums of p_T) in control regions

- Used in profile likelihood fit to constrain backgrounds



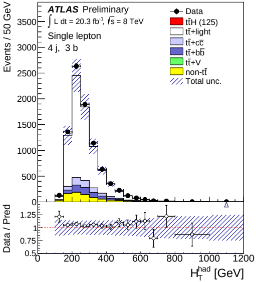
$t\bar{t}H \rightarrow b\bar{b}$: Systematic uncertainties

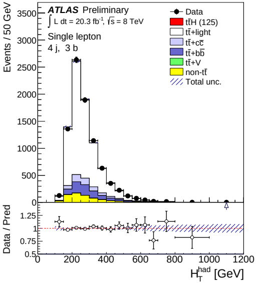
Main challenge: control of $t\bar{t}$+jets

- Large normalization uncertainties
  - 6% on $t\bar{t}$ normalization
  - 50% on $t\bar{t}+b\bar{b}$ and $t\bar{t}+c\bar{c}$
- High statistics control regions constrain normalizations
  - Unc on $t\bar{t}+b\bar{b}$ ($t\bar{t}+c\bar{c}$) reduced to 15% (29%)
- Additional shape uncertainties from:
  - MC generators, parton showers, PDF
  - unfolded ATLAS $t\bar{t}$ measurements (arXiv:1407.0371 [hep-ex])

Other systematics

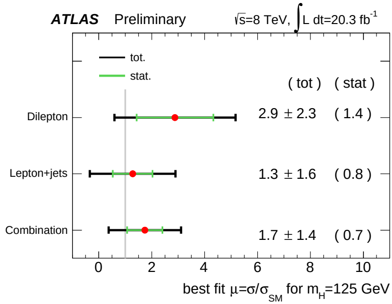
- Small impact from other backgrounds and signal modelling, except $t\bar{t}+Z$ cross-section
- Major influence of b-tagging systematics
  - Especially light jets mistag efficiency (large uncertainty)
- Significant role of Jet energy scale systematics

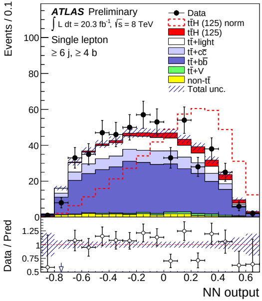


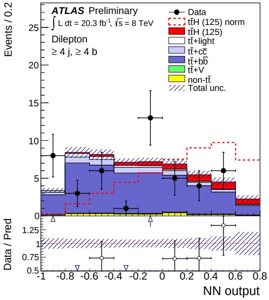


Results

- Observed signal strength $\hat{\mu} = 1.7 \pm 1.4$, compatible between single-lepton and dilepton channels
- 95% CLs limits: 4.1 observed, for expected 3.4 if $\mu = 1$





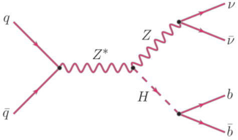


$VH \to b\bar{b}$: Presentation

Analysis divided into 3 channels

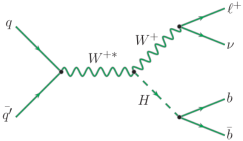
0 lepton

- High E_T^{miss} ($> 120\,GeV$)
- Anti-MJ cuts: E_T^{miss} and p_T^{miss}



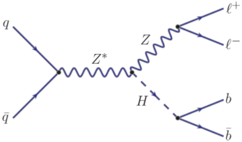
1 lepton

- 1 high-p_T (25 GeV) isolated lepton
- Anti-MJ cuts: m_T^W and E_T^{miss}



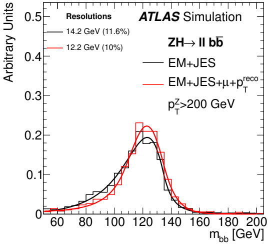
2 leptons

- 2 opposite-sign high-p_T (25, 10 GeV) leptons
- Anti-top cuts: Z mass window 8 GeV, $E_T^{miss} < 60$ GeV



Common selections

- 2 or 3 high-p_T jets (45, 20 GeV)
- of which 2 b-tagged (70% efficiency)
- Specific improvements to b-jet resolution
- $\Delta R(b\bar{b})$ cuts for background rejection



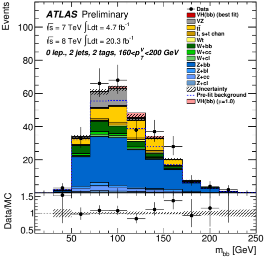
$VH \rightarrow b\bar{b}$: Categorization

Analysis divided into numerous categories

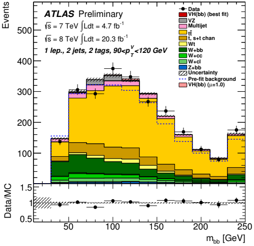
- p_T^V categorization: improvement of S/B
- Signal Regions (SR): $m_{b\bar{b}}$ used as discriminant variable
- Control Regions (CR): total yields only

Channel	Nb p_T^V bins	2jets, 1tag	3jets, 1tag	2jets, 2tags	3jets, 2tags	e-μ CR
0-lepton	3	CR	CR	SR	SR	–
1-lepton	5	CR	CR	SR	SR	–
2-lepton	5	CR	CR	SR	SR	CR

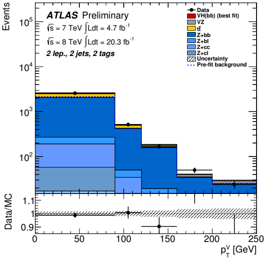
- e-μ CR: 1 electron, 1 muon, $m_{\ell\ell} > 40$ GeV



SR: 0lep, 2tag 2jet, $160 <$ TeV < 200 GeV



SR: 1lep, 2tag 2jet, $90 < p_T^V < 120$ GeV



CR: 2lep, 1tag 2jet

$VH \to b\bar{b}$: Background modelling

VH analysis: low S/B and diverse background sources

V+jets

- Correction of $\Delta\Phi(jj)$ improves modelling for Z+jets and W+jets
- Systematics on most important variables: $\Delta\Phi$, $m_{b\bar{b}}$, flavour composition
  - from MC generators and data studies

$t\bar{t}$

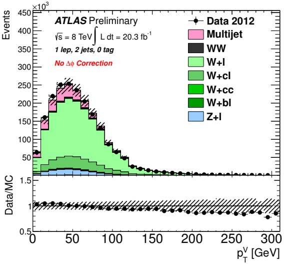
- Correction of top p_T from unfolded measurement
- Large $t\bar{t}$ phase space probed in the analysis
  - Modelling systematics allow sufficient flexibility

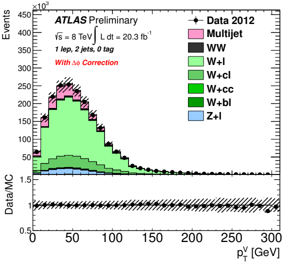
Multijet

- Estimated with data-driven methods
- Significant only in 1 lepton channel

Single-top, diboson

- Estimated from Monte Carlo





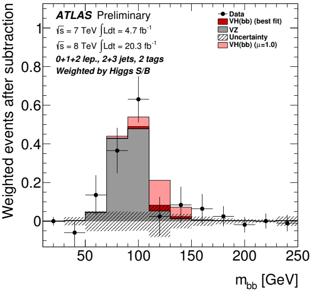
$VH \rightarrow b\bar{b}$: Diboson Peak

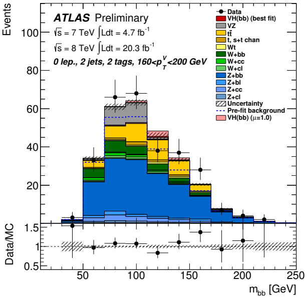
Check of the profile likelihood

- Very good check of validity of modelling and fit
- $WZ+ZZ$ as signal
- Higgs at 125 GeV treated as background
- Measure $\mu_{VZ} = 0.9 \pm 0.1\text{(stat)} \pm 0.2\text{(syst)}$
- Significance 4.8σ (5.1σ expected)

Main systematics on Higgs fit

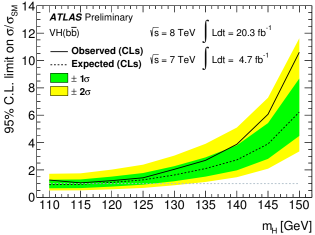
- $t\bar{t}$ modelling
- b and c-tagging efficiencies
- Signal modelling
- Overall background uncertainty $\sim 3\%$ after profiling

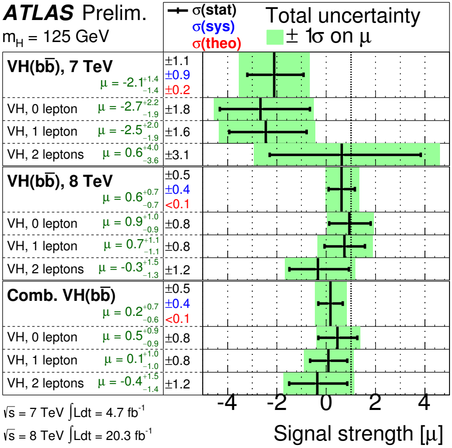




Combined results

- No excess observed
- $\mu_H = 0.2 \pm 0.5(\mathrm{stat}) \pm 0.4(\mathrm{syst})$
- Compatible with both signal and background hypotheses
- Observed (exp) limit at 125 GeV: 1.4 σ_{SM} (1.3)





Extrapolation of the analysis to high luminosities (ATL-PHYS-PUB-2014-011)

- Evidence at 3.9 σ expected from 1 and 2 lepton channels with 300 fb^{-1}, $\sqrt{s} = 14\,TeV$

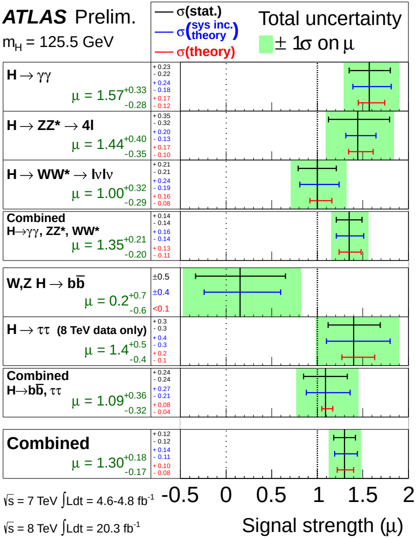
Conclusions

Very rich results on Higgs fermion decays in ATLAS Run1 data

- Evidence at 4.1 σ of $H \to \tau^+\tau^-$ decay mode
- Limits set in $H \to \mu^+\mu^-$ mode (7.0 SM): no strong deviation in lepton couplings
- No signal observed in $t\bar{t}H$ and $VH \to b\bar{b}$ modes, but results compatible with SM Higgs: $\hat{\mu} = 1.7 \pm 1.4$ and 0.2 ± 0.7 respectively

Combined evidence for fermion decays (ATLAS-CONF-2014-009)

- $H \to \tau^+\tau^-$ and $VH \to b\bar{b}$ combined excess of 3.7 σ
- Result compatible with SM expectation:
  - $\hat{\mu} = 1.09^{+0.36}_{-0.32}$



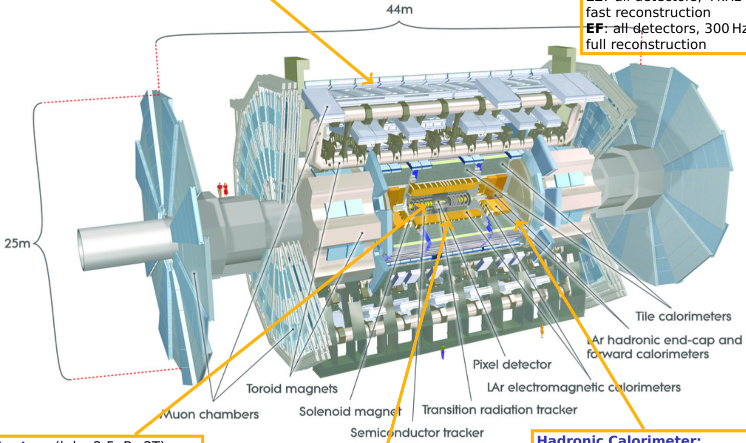
Updates of some analyses are expected: stay tuned for further results !

Additional material

The ATLAS detector

Muon Spectrometer: ($|\eta| < 2.7$)
Air toroid with drift chambers,
Provides μ trigger and momentum measurement,
Resolution $< 10\%$ up to $p \sim 1$ TeV.

Trigger System:
3 levels
L1: calo and muons, 75 kHz
dedicated electronics
L2: all detectors, 4 kHz
fast reconstruction
EF: all detectors, 300 Hz
full reconstruction



Inner Detector: ($|\eta| < 2.5$, B=2T)
Si Pixels, SCT, TRT
Precision tracking,
Vertex reconstruction,
e/π separation
$\sigma/p_T \sim 3.8 10^{-4} p_T \oplus 0.015$

EM Calorimeter: ($|\eta| < 3.2$)
Pb-LAr, accordion structure
Provides trigger on e/γ,
Identification and measurement
$\sigma/E \sim 10\%/\sqrt{E} \oplus 0.7\%$

Hadronic Calorimeter:
Scint/Fe tiles in barrel ($|\eta| < 1.7$)
W/Cu-LAr in endcaps ($|\eta| < 4.9$)
Provides jet trigger and energy measurement,
$\sigma/E \sim 50\%/\sqrt{E} \oplus 3\%$
Hermetic coverage for MET

$H \to \mu^+\mu^-$: Categorization

7 categories in the $H \to \mu^+\mu^-$ analysis

Central muons, $p_T^{\mu\mu} < 15$ GeV	Non-central muons $p_T^{\mu\mu} < 15$ GeV	VBF ≥ 2 jets $m_{jj} > 500$ GeV $\Delta\eta_{jj} > 3$ $\eta_{j1} \times \eta_{j2} < 0$
Central muons, $15 < p_T^{\mu\mu} < 50$ GeV	Non-central muons $15 < p_T^{\mu\mu} < 50$ GeV	
Central muons, $p_T^{\mu\mu} > 50$ GeV	Non-central muons $p_T^{\mu\mu} > 50$ GeV	

$VH \to b\bar{b}$: High lumi analysis

Method

- Truth studies based on current $VH \to b\bar{b}$ analysis
- 1 and 2 lepton channels
- Smearing functions, pile-up dependent
- Validation with 8 TeV analysis
- Lumi: $\sqrt{s} = 14\,TeV$, 300fb^{-1}, $<\mu>= 60$, and 3000fb^{-1}, $<\mu>= 140$

Scenarios

- Systematics estimated for high pile-up
- 2 scenarios for JES (main syst 1 lepton)
- Additional scenario for analysis improvements

Results

- 300 fb^{-1}, $<\mu>= 60$:
  - With improvements: 4.1σ (25% precision on μ)
- 3000 fb^{-1}, $<\mu>= 140$:
  - With improvements: 9.6σ (13% precision on μ)