Measurement of cross sections and couplings of the SM Higgs boson in the WW decay channel using the ATLAS detector

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on behalf of ATLAS Collaboration
Higgs boson production/decay

- Higgs boson couplings measurement essential SM consistency test
- Search for rare production modes
  - Continue search for additional states at high mass in parallel

- WW channel well-suited to exploring rare production modes and searching at high-mass
  - Large branching ratio: 22 %
  - Good S/B from clean dilepton signature
$H \rightarrow WW^* \rightarrow l\ell\nu\nu$ Signature

**Final state:**
- 2 charged leptons
- 2 neutrinos
- $n_{jets}$ depend on the production mode

**Spin zero Higgs:** charged leptons prefer to point in same direction

- Signal process can not be fully reconstructed $\rightarrow$ presence of neutrino
- A transverse mass $m_T$ can be calculated without the unknown longitudinal neutrino momenta

$$M_T^2 = (E_T^{\ell\ell} + E_T^{miss})^2 - (\vec{p}_T^{\ell\ell} + \vec{E}_T^{miss})^2$$
Analysis strategy

- Categorise events by number of jets, number of leptons, lepton flavors
- Separate by production mode and background composition
- Cut away backgrounds and normalise to control regions enriched in a particular background but orthogonal to the signal region
Backgrounds

- **WW**: dominant ggF background → almost irreducible
- **Top**: coming from unidentified b-quark
- **DY**:
  - $Z/\gamma^* \rightarrow e\mu$: Misidentified missing energy
  - $Z/\gamma^* \rightarrow \tau \tau$: Irreducible
- **Misid**: jet misidentified as lepton
  - “fake” leptons, particularly muons, are often true leptons from heavy-flavor hadron decays
- **dijet data samples are use to obtain the fake factor**
  - 40-45% uncertainty on fake factor from sample composition
**Backgrounds**

### WW background

**ATLAS**

\[ \sqrt{s} = 8 \text{ TeV}, \ 20.3 \text{ fb}^{-1} \]

- \( N_{\text{Jets}} < 2 \) analyses use \( m_{ll} \) to define the CR
- \( N_{\text{Jets}} > 1 \) categories have a large contribution from top-quark background
- Invariant mass of the charged leptons combines angular information with the kinematic information associated with Higgs boson mass \( \rightarrow \) powerful discriminant

### Top background

**ATLAS**

\[ \sqrt{s} = 8 \text{ TeV} \]

- Light-quark jet from initial-state radiation and a b-quark jet that is not identified by the b-tagging algorithm
- CR requires exactly one b-tagged jet to mimic this topology

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H $\rightarrow$ WW* $\rightarrow$ ll$\nu\nu$ signal strength

\[ \mu_{ggF} = 1.02 \pm 0.19 +0.22 \ -0.18 = 1.02 +0.29 \ -0.26 \quad \text{(stat)} \quad \text{(syst)} \]

\[ \mu_{VBF} = 1.27 +0.44 \ -0.40 +0.30 \ -0.21 = 1.27 +0.53 \ -0.45 \quad \text{(stat)} \quad \text{(syst)} \]

- $\mu = \sigma/\sigma_{SM}$ //measured cross section $\sigma = \mu \star \sigma_{SM}$

- Fiducial cross section not affected by the theoretical uncertainties on the total signal yield

- Confirmed Higgs boson decay to W bosons $\rightarrow$ rate consistent with the Standard Model : observed significance of 5.8 standard deviations

- Evidence of VBF production in this channel $\rightarrow$ observed significance of 3.2 standard deviations
**VH → WW Signal Regions**

*Clean 3-lepton (WH) and 4-lepton (ZH) signatures, additional info on HWW vertex (complement to VBF mode) → pure HWW or HZZ*

### WH → 3-leptons
- Major backgrounds are WZ/Wγ*, ZZ*, VVV
- Split into Z enriched and Z depleted regions using number of same flavour (SF) opposite sign (OS) lepton pairs

### ZH → 4-leptons:
- 2 OS pairs, one with |mll - mZ| < 10 GeV 1 event expected, S/B ~ 1/5 zero observed
- Main background is ZZ*
- Split SR into 1SFOS and 2SFOS to better control ZZ* bkg
Combined $H \rightarrow WW$ Results ($m_H = 125.36$ GeV)

- Observed significance for the combined VH production is 2.5 standard deviations
- Significance of 0.9 standard deviations is expected in the SM Higgs boson hypothesis
Differential Cross Sections

- Possible to directly measure several kinematic distributions in a close to model independent way

- Compare to theoretical models and provide constrains on QCD and PDF calculation

- Sensitive to new physics

- Analysis performed only on different flavour

- Use control region to extract background and subtract the predicted background in the signal region from the data

- Correction/extrapolation of the event yields from the reconstructed signal region to the truth-level fiducial volume

- Unfolding corrects measured distribution for detector effects and brings it from the signal (reconstructed) to the fiducial (particle level) volume

\[
\frac{d\sigma}{dX_i} = \frac{1}{\mathcal{L} \times BR} \frac{M^{-1}_{ji} \epsilon_{fid,j}}{\epsilon_{truth,sel,i}} (N_j - B_j)
\]
Differential Cross Sections

- Jet multiplicity $N_{\text{jets}}$: a measure of the QCD radiative process in the initial state. Reflects the hard QCD process, calculations lack precise prediction for the high $N_{\text{jets}}$

- Statistical uncertainties (25%-75%) still dominate all the differential measurements
Differential Cross Sections

- Transverse momentum $p_T^H$ directly probes perturbative/soft QCD, sizeable uncertainties at low $p_T$

- Statistical uncertainties (25%-75%) still dominate all the differential measurements
Summary

- WW was essential to discovery, combined rate measurement, and connecting the new particle to electroweak symmetry breaking

- WW channel can be very useful in investigation the Higgs boson nature
  - Good S/B and large branching ratio
  - Challenging backgrounds in ggF and VBF

- ggF and VBF modes key inputs to coupling measurement combinations

- Search for rarer production modes: WH, ZH

- Total fiducial cross BR is obtained by summing the three bins on the Njet distribution

\[ \sigma_{ggF}^{\text{fid}} = 36.0 \pm 7.2(\text{stat}) \pm 6.4(\text{sys}) \pm 1.0(\text{lumi}) \text{ fb} \]

- The Run 2 data will significantly reduce the statistical uncertainties on the measurements. Future precise measurement will provide more stringent tests of the SM predictions of the Higgs boson properties
Backup
Differential Cross Sections

- Longitudinal angle $\Psi_{ll}$: depends on QCD radiative corrections and PDF. Substantial uncertainties on gluon PDFs for low $x$, high $x$ and high $Q^2$

- Statistical uncertainties (25%-75%) still dominate all the differential measurements