論文の内容の要旨

論文題目：Measurement of the Higgs boson couplings using the $WW^* \to \ell\nu\ell\nu$ final state

($WW^* \to \ell\nu\ell\nu$ 終状態を用いたヒッグスボソン結合定数の測定)

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The Standard Model of particle physics (SM) is an elegant theory of elementary particles and their interactions. It has been tested in various aspects by many experiments, and has been accomplished as a local gauge invariant theory. In the SM there was a theoretical obstacle when considering mass of weak bosons, since all particles in the gauge theory are massless. In 1960's it has been demonstrated by R. Brout, F. Englert, and P. Higgs that the weak bosons acquire their own mass interacting with a scalar boson, so-called the Higgs boson, through the Brout-Englert-Higgs (BEH) mechanism. The Higgs search has a long history since 1960's. However the direct searches performed by LEP and Tevatron experiments eventually did not find the Higgs boson.

In order to perform continuous search for the Higgs boson, the LHC accelerator was constructed at CERN and started pp collision in 2010. The LHC-ATLAS experiment has recorded 4.5 fb^{-1} of 7 TeV data in 2011 and 20.3 fb^{-1} of 8 TeV data in 2012. On 4th July 2012, the ATLAS and CMS collaborations announced that they had each observed a new particle consistent with the SM Higgs boson, with a mass of approximately 125 GeV. The focus of physics analysis at the LHC is now the measurement of the properties of the new boson. For example, the spin-0 nature of the new boson has been tested, excluding other spin models (e.g. spin-1 and spin-2) using $\gamma\gamma$, $ZZ^* \to 4\ell$, and $WW^* \to \ell\nu\ell\nu$ channels [1]. The measurement of the Higgs couplings to fermions and weak bosons are also of special interest.

In this thesis, the measurements of the couplings using the $H \to WW^* \to \ell\nu\ell\nu$ final state are presented with the full Run-I pp collision data corresponding to 20.3 fb^{-1} of 8 TeV and 4.5 fb^{-1} of 7 TeV, recorded by the ATLAS at the LHC. In the $H \to WW^* \to \ell\nu\ell\nu$ channel the Higgs boson signature contains two genuine isolated high p_{T} leptons from W boson decays and a large missing transverse energy from two neutrinos, thus the analysis starts from the di-lepton dataset, imposing the missing transverse energy.

The $H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$ analysis is optimized for each production process, gluon-gluon fusion (ggF) and vector boson fusion (VBF) production processes, by separating into bins of jet multiplicity. However the analysis suffers from many backgrounds such as Standard Model WW, top ($t\bar{t}, Wt$), W+jets and other diboson ($WZ/ZZ, W\gamma^{(*)}$), referred to as VV backgrounds. One of the most significant backgrounds is the W+jets backgrounds, where a W boson produced in association with a jet that is misidentified as a lepton, due to its large systematic uncertainty (that was 40-60%), making it an important limitation to the experimental sensitivity. The previous analysis [2] employed tight lepton selection, making the W+jets background as small as possible. Nevertheless it was found that the analysis was limited by large statistical uncertainty as shown in Table 1.

Table:1 Leading uncertainties on the signal strength μ in the previous analysis [2].

Category	Source	Uncertainty, up (%)	Uncertainty, down (%)
Statistical	Observed data	+21	−21
Theoretical	Signal yield and acceptance	+15	−11
Theoretical	WW normalization	+12	−12
Experimental	Objects and DY estimation	+9	−8
Experimental	MC statistics	+7	−7
Experimental	W+jets fake factor	+5	−5
Others	luminosity, other backgrounds	+6	−6
Total		+32	−29

To improve the statistics in a given integrated luminosity, the analysis presented in this thesis employs looser lepton selection. The looser selection, however, increases the W+jets and VV backgrounds by more than a factor of two. In order to solve such a dilemma, more sophisticated procedures on the modeling of these backgrounds are developed.

For the W+jets estimate, a data-driven method is used because the misidentified lepton may not be accurately modeled in simulation. The W+jets background is estimated from the W+jets control sample applying extrapolation factor (fake factor). The W+jets control sample is defined as events that have one identified lepton and one misidentified lepton, and the fake factor is measured in the multijets-enriched data sample. The largest uncertainty arises from the extrapolation due to the fact that a jet flavor composition of the multijets sample is different from that of the W+jets sample. The new procedure uses Z+jets sample instead of the multijets sample when measuring the fake factor, which leads to smaller uncertainty (20-60%) on the extrapolation because the flavor composition of the Z+jets sample is much closer to that of the W+jets sample.

For the VV estimate, same-sign events are used to normalize the VV background. The same-sign events that pass the same selection criteria as the signal region but are required to be the same signed two leptons, provide a good validation region for the VV backgrounds because the same-sign region is dominated by the VV backgrounds. Adding the same-sign region to the fit as a control region allows the fit to cancel some of the uncertainties on the VV backgrounds because the uncertainties are common between the same-sign region and opposite-sign region (i.e. signal region).

The results presented in this thesis supersede the previous measurement by $> 50\%$ on the experimental sensitivity. The large improvement is achieved owing to optimizations of selection of physics objects and better modeling of the W+jets and VV backgrounds. After all selection criteria applied transverse mass distribution is used as a final discriminant for the fit. Figure 1 shows transverse mass distribution after all selections and before performing the fit (pre-fit).

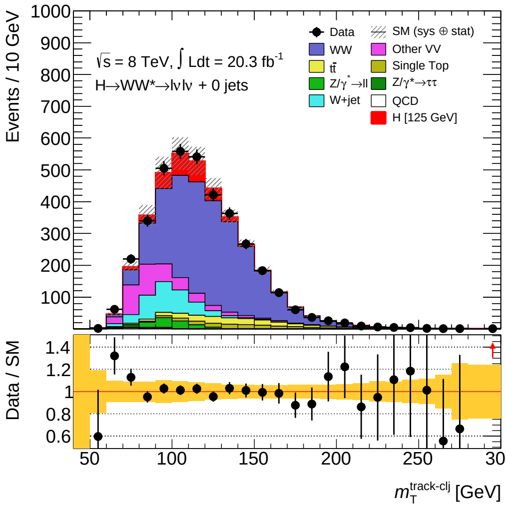

Figure:1 Transverse mass distribution for the ggF 0-jet analysis after all selections and before performing the fit (pre-fit). The Data/SM ratio includes signal yields predicted by the Standard Model ($\mu = 1$). The yellow band includes both statistical and systematic uncertainties.

The Higgs couplings are represented by signal strength μ that is defined as the ratio of cross section times branching fraction in data to that in theoretical prediction given by :

$$\mu = \frac{(\sigma \cdot \mathrm{BR}(\mathrm{H} \to \mathrm{WW}^* \to \ell\nu\ell\nu))_{\text{ data}}}{(\sigma \cdot \mathrm{BR}(\mathrm{H} \to \mathrm{WW}^* \to \ell\nu\ell\nu))_{\text{ Theory(SM)}}}, \tag{1}$$

where σ is cross section of the Higgs production and $\mathrm{BR}(H \to WW^* \to \ell\nu\ell\nu)$ is branching fraction of the Higgs decay into $WW^* \to \ell\nu\ell\nu$. Assuming that there is no contribution from beyond the Standard Model (BSM) particles that can couple to the Higgs boson, the signal strength is expected to be unity, while if there exists the BSM particle, one can see a deviation on the signal strength.

The signal strentgh is measured for the individual processes μ_{ggF} and μ_{VBF}. The measured μ values for $m_{\mathrm{H}} = 125$ GeV are :

$$\begin{aligned} \mu_{\mathrm{ggF}} &= 1.15^{+0.30}_{-0.26}, \\ \mu_{\mathrm{VBF+VH}} &= 1.36^{+0.55}_{-0.47}. \end{aligned} \tag{2}$$

The comparison of indivdual signal strengths is meaningful because the couplings of these production processes are different. The ggF production contains the Higgs coupling with top quark (or bottom quark), namely Yukawa coupling, in addition to the coupling with weak bosons. While the VBF production contains only electroweak (EW) vertices in the leading order, thus the VBF process indicates the couplings with purely weak bosons. Eventually the coupling to fermions and weak bosons are each extracted by introducing new parameterization of the coupling strentghs, κ_F for fermions and κ_V for the weak bosons. The measured κ_V and κ_F values for $m_{\mathrm{H}} = 125$ GeV are :

$$\begin{aligned} \kappa_V &= 1.08^{+0.11}_{-0.11}, \\ \kappa_F &= 1.00^{+0.32}_{-0.24}. \end{aligned} \tag{3}$$

where the measurements of an accuracy of $\sim$ 15% for weak bosons and of $\sim$ 50% for fermions are achieved. Corresponding two-dimensional likelihood contours in the κ_V and κ_F plane are also shown in Figure 2. The measured observables, μ and κ, are consistent with unity, namely consistent with the values predicted by the Standard Model.

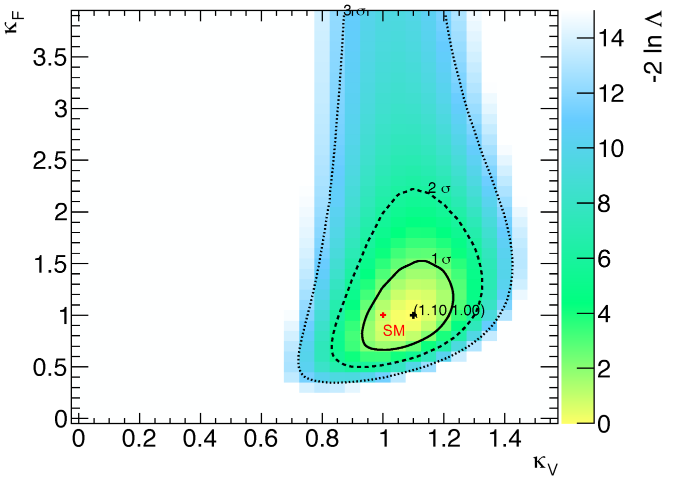

Figure:2 Likelihood contours in the κ_V and κ_F plane for $m_{\mathrm{H}} = 125$ GeV. The best-fit values to data and the 68% (solid) and 95% CL (dotted), as well as the SM prediction (1,1) are explicitly shown.

Reference

[1] ATLAS Collaboration, "Study of the spin properties of the Higgs-like boson in the $H \to WW^{(*)} \to e\nu\mu\nu$ channel with 21 fb^{-1} of $\sqrt{s} = 8$ TeV data collected with the ATLAS detector", ATLAS-CONF-2013-031.

[2] ATLAS Collaboration, "Measurements of the properties of the Higgs-likeboson in the $WW^{(*)} \to \ell\nu\ell\nu$ decay channel with the ATLAS detector using 25 fb^{-1} of proton-proton collision data", ATLAS-CONF-2013-030.