Muon Isolation Studies in Higgs Boson Decays with the ATLAS Detector at the LHC

G. Reiter, O. Biebel, G. Duckeck, J. Elmsheuser, F. Fiedler, G. Krobath, M. Lambacher, M. Lamprecht, R. Mameghani, T. Nunnemann, B. Ruckert, D. Schaile, M. Schott, C. Serfon, and R. Ströhmer

In the Standard Model (SM), the hypothetical Higgs boson is crucial for the understanding of electroweak symmetry breaking (EWSB) and the mass generation of electroweak gauge bosons and fermions. Spontaneous EWSB predicts the existence of this neutral scalar particle with an unpredicted mass M_H. Direct searches at the CERN e^+e^- collider (LEP) yield a lower limit for the Higgs boson mass of $M_H > 114.4\,\text{GeV}$ at the 95% confidence level (CL). Indirect measurements via fits to the electroweak precision data give an upper bound of $M_H < 186\,\text{GeV}$ at the 95% CL. If the SM Higgs boson exists, it will be produced at the CERN Large Hadron Colider (LHC).

For a Higgs boson mass of $M_H > 140\,\text{GeV}$ $H \to W^+W^-$ is the dominant decay channel. In this report, a study of the muon isolation is presented for the decay channel $H \to W^+W^- \to \mu^+\mu^-\nu_\mu\bar{\nu}_\mu$, using $M_H = 170\,\text{GeV}$. In the final state there are two isolated muons with high transverse momentum. To distinguish between the Higgs-signal and background from QCD- and $t\bar{t}$-decays, the isolation of the muon track is an appropriate criterion. So for this analysis cuts on different isolation variables are studied with respect to signal efficiencies and signal-to-background-ratios. The isolation of the muons originated in the Higgs boson decay is expected to be similar to those in the well-known decay $Z \to \mu^+\mu^-$, so this channel is studied as a reference.

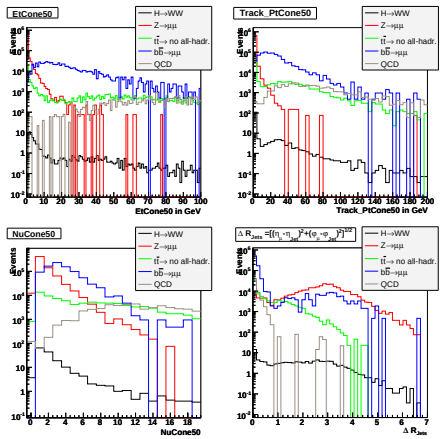

Fig. 1: Studied isolation variables for analysed signal- and background-processes

The isolation variables studied are the calorimeter energy ($EtConeX = (\sum_{cells\ within\ dR} E_{cell}) - E_\mu$), the number of tracks ($NuConeX$) and the sum of the transversal momenta of all tracks ($Track\_PtConeX = \sum_{\Delta R_{Track \neq \mu} < dR}(p_{T,Track})$) within a defined cone around the muon. In addition the distance of the muon to the nearest jet ($\Delta R_{Jet} = \sqrt{(\eta_\mu - \eta_{Jet})^2 + (\varphi_\mu - \varphi_{Jet})^2}$) has been chosen as a further isolation variable. Figure 1 shows the four variables (for a middle-sized cone of $dR = 0.5$) for the studied signal- and background-processes. Only well reconstructed muons with a transverse momentum $p_T > 15$ GeV for the leading and $p_T > 10$ GeV for the trailing muon are selected. All plots show quantities for the leading muon with a normalisation to an integrated luminosity of $1 fb^{-1}$.

Isolation variables with small cone-sizes are more efficient for the rejection of QCD/$b\bar{b}$-background in terms of signal-to-background ratio. Events from $t\bar{t}$-production have a better rejection with larger cone-sizes. Looking at the ratio of the number of signal over the square root of background events ($S/\sqrt{B}$) for different cuts, however, middle- and large-sized cones yield the best values for all backgrounds.

Figure 2 (a)-(c) show $S/\sqrt{B}$ for different cuts on the isolation variables with middle cone-size for the studied backgrounds, where the cut number on the x-axis belongs to cut-values in the range of 90 to 4 GeV for $EtCone50$ and $Track\_PtCone50$, 0.1 to 2.2 for ΔR_{Jet} (in non-equidistant steps) and 17 to 2 for $NuCone50$. For comparison, Figure 2 (d) shows the signal-efficiency for these cuts.

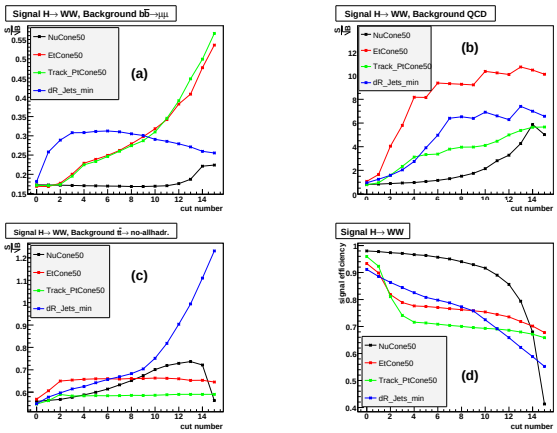

Fig. 2: (a)-(c): Comparison of $S/\sqrt{B}$ for cuts on the different isolation variables for the Higgs-signal and three studied backgrounds; (d): Efficiency of the Higgs-signal for cuts on the different isolation variables

Getting a high value of $S/\sqrt{B}$ leads to a smaller signal-efficiency. Table 1 summarizes the values of $S/\sqrt{B}$ and the signal efficiency for a set of isolation variables and a particular choice of cuts.

Cut	$b\bar{b}$ $S/\sqrt{B}$	QCD $S/\sqrt{B}$	$t\bar{t}$ $S/\sqrt{B}$	signal eff.
without cut	0.176	0.682	0.494	100%
$\Delta R_{Jet} > 1.0$	0.213	6.327	0.756	84%
$EtCone50 < 7$ GeV	0.383	10.11	0.660	74%
$Track50 < 7$ GeV	0.391	4.993	0.591	69%
$NuCone50 < 6$	0.170	2.813	0.719	89%

Table 1: Examples for the quality of cuts on the analysed isolation variables

In summary, the isolation variable $EtConeX$ yields the best rejections for backgrounds from QCD/$b\bar{b}$ production, whereas $t\bar{t}$ events are best suppressed with a cut on ΔR_{Jet}.