Higgs boson coupling measurements at the LHC using $H \to \tau\tau$ decays

Chris Boddy, Sinead Farrington and Chris Hays

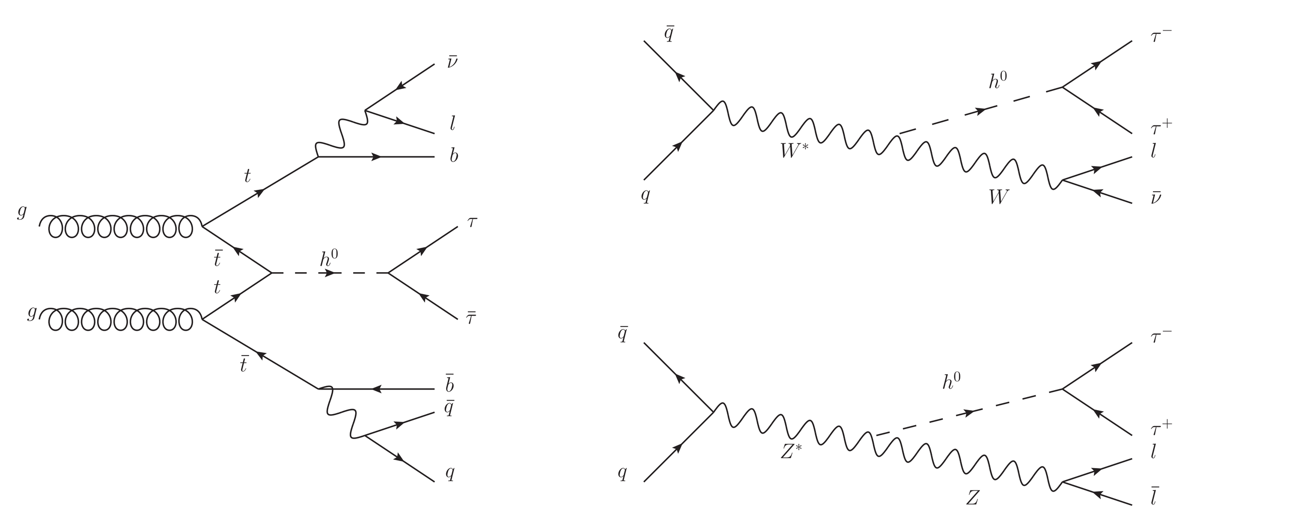
University of Oxford

Introduction

Experiments at the LHC will soon be able to detect signs of the Standard Model (SM) Higgs boson in a variety of production channels and are expected to claim its discovery with $\leq 10\,\mathrm{fb}^{-1}$ of 14 TeV pp collision data.

Prospects for initial Higgs boson discovery at the LHC have been studied extensively while low-rate processes observable with the full LHC design luminosity have not been completely explored.

We investigate the sensitivity of the ATLAS and CMS experiments to an SM Higgs boson produced in association with W, Z, or $t\bar{t}$, and decaying to $\tau\tau$, for datasets of 50 fb^{-1} each.



Method

Since each tau lepton can decay either hadronically or leptonically, there are different final states to be searched for from each production channel. Additionally, there are several different SM background processes that must be considered for each of these analyses.

Using the **Sherpa** Monte Carlo generator [1] combined with NLO cross section calculations from MCFM [2] and the **Delphes** reconstruction [3], we use realistic detector acceptance, trigger and identification efficiencies [4] as part of a simple cut-based analysis.

Object	ID efficiency (%)	Jet mis-identification rate (%)	Trigger efficiency (%)
e	64.2	0.0108	65
μ	94.2	0.169	90
τ_h	40	2.3	lepton triggers used

An example of the reconstructed object selection criteria are shown in the table below for the WH events, with two leptons and one τ_{jet} (all momenta and masses are in GeV).

$P_T^{l_1}$	$P_T^{l_2}$	$P_T^{\tau_{jet}}$	$\not{E}_T$	$m_{l^+l^-}$	$\lvert\sum_{charges}\rvert$	$\sum \overrightarrow{P_T}$
25	15	25	$20 < \not{E}_T < 100$	< 76 or > 106	1	< 60

Sample Results

The number of expected signal and background events expected with $\mathcal{L} = 100\,\mathrm{fb}^{-1}$ at $m_H = 120$ GeV/c^2.

Process	Final state		
	4 jets, $2\tau_{jet}$, 2 lep	4 jets, $1\tau_{jet}$, 3 lep	4 jets, 4 lep
$t\bar{t}Z(\to\tau\tau)$	7.2	23.5	4.2
$t\bar{t}Z(\to ee/\mu\mu)$	0.4	1.9	4.4
$t\bar{t}$ + jets	7.4	13.1	1.6
$\sum$ background	14.7	38.5	10.3
$\mathbf{t\bar{t}(\to l\nu q\bar{q}'b\bar{b})H(\to\tau\tau)}$	9.1	32.6	6.2

Process	Final state		
	2τ, 2 lep	$1\tau_{jet}$, 3 lep	4 lep
$Z(\to ll/\tau\tau)Z(\to\tau\tau)$	27.25	78.0	22.0
$Z(\to\tau\tau)$ +jets	0.1	0.6	0.02
$t\bar{t}$	0.1	0.2	0.02
$\sum$ background	27.4	78.9	22.0
$\mathbf{Z(\to ll)H(\to\tau\tau)}$	13.6	30.3	8.0

Process	Final state	
	$1\tau_{jet}$, 2 lep	3 lep
$W(\to l\nu)Z(\to ll)$	63.3	264.8
$W(\to l\nu)Z(\to\tau\tau)$	457.5	142.6
$W(\to l/\tau\nu)$ +jets	9.6	1.25
$Z(\to ll/\tau\tau)$ +jets	28.7	4.63
$t\bar{t}$	483.6	145.9
$\sum$ background	1042.0	559.3
$\mathbf{W(\to l\nu)H(\to\tau\tau)}$	202.6.	56.8

Cross Section and Couplings

Combining these channels with previous studies, improves the expected LHC sensitivity to the following quantities:

1. the ratio of the WWH to ZZH couplings, fixed by SU(2) in the SM;
2. the Yukawa coupling ratios g_{Htt}/g_{HWW} and $g_{H\tau\tau}/g_{HWW}$, determined by the top-quark and tau-lepton masses, respectively, and separately sensitive to the source of mass for up- and down-type fermions;
3. the Yukawa coupling ratio $g_{Hbb}/g_{H\tau\tau}$, determined by the bottom-quark and tau-lepton masses, and sensitive to differences in the source of mass for quarks and leptons.

The couplings are simply related to measured cross sections $\times\mathcal{BR}$ by

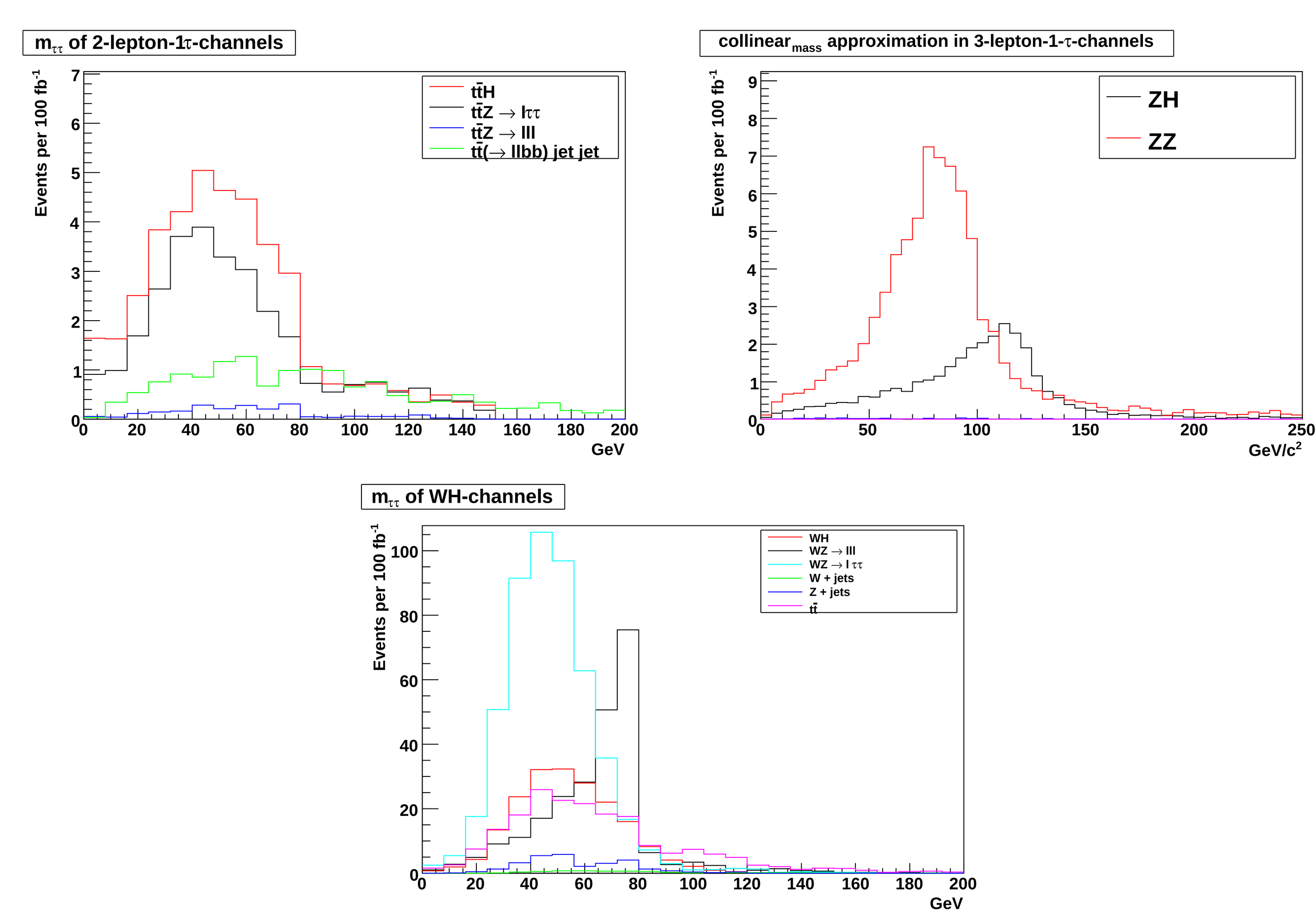
$$\frac{\sigma(pp\to W,Z,t\bar{t}H)\frac{\Gamma_{\tau\bar{\tau}}}{\Gamma_{total}}}{\sigma(pp\to W,Z,t\bar{t}H)\frac{\Gamma_{b\bar{b},WW}}{\Gamma_{total}}} = \frac{\Gamma_{\tau\bar{\tau}}}{\Gamma_{b\bar{b},WW}} = \frac{y_\tau^2}{y_{W,b}^2}$$

We thus determine the expected LHC sensitivity to:

$$\sigma_{WH}\times\frac{\Gamma(H\to\tau\bar{\tau})}{\Gamma_{total}}\ ,\sigma_{ZH}\times\frac{\Gamma(H\to\tau\bar{\tau})}{\Gamma_{total}}\ ,\sigma_{t\bar{t}H}\times\frac{\Gamma(H\to\tau\bar{\tau})}{\Gamma_{total}}$$

Mass Reconstruction

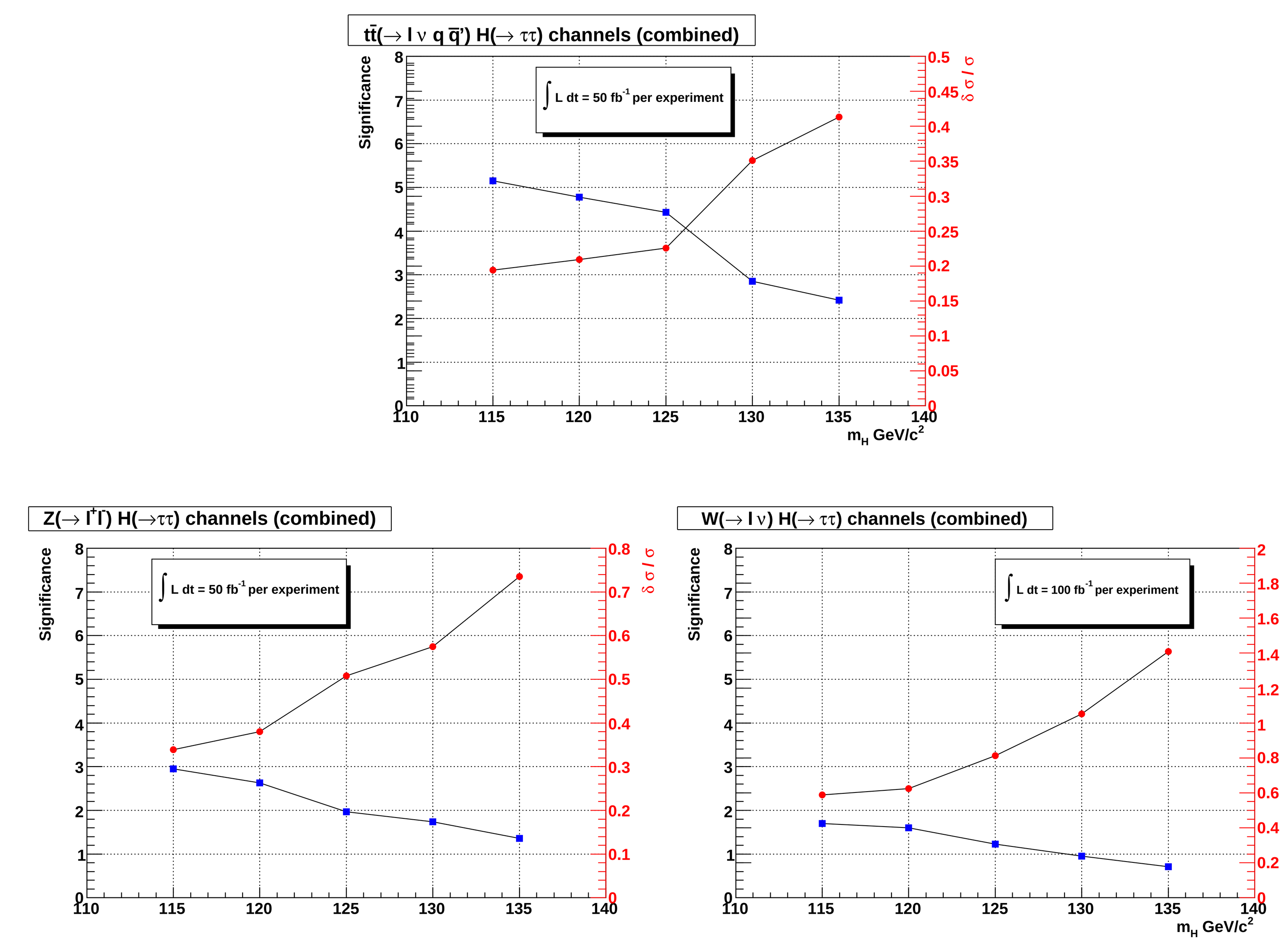
Since momentum is carried away by at least two neutrinos in these events, conventional mass reconstruction is not possible. The invariant mass of the visible tau decay products is used to create templates in the ttH and WH analyses while the collinear mass approximation is used in the ZH analysis to reconstruct the $\tau^+\tau^-$ mass.



Pseudo-experiments are generated from signal and background MC distributions according to a Poisson distribution, $P(k;\lambda) = \frac{\lambda^k \exp^{-\lambda}}{k!}$, for k observed events and λ expected events. The number of signal events is extracted by minimising the log-likelihood as a function of the signal yield.

Likelihood Fit Results

The expected statistical significance and corresponding uncertainty on the calculated $\sigma_{(WH,ZH,t\bar{t}H)}\times\Gamma_{H\to\tau\tau}$ are calculated for a range of input Higgs masses for a given integrated luminosity, assuming a 10 % systematic uncertainty on the background yield.



The prospects for measuring the Higgs boson couplings at the LHC are good in certain channels. We plan to further refine the selection criteria to improve the expected significance.

References

[1] T. Gleisberg *et al.*, J. High Energy Phys. **0902**, 007 (2009). We use version 1.2.1.

[2] J. M. Campbell and R. K. Ellis, hep-ph/9905386 (1999)

[3] S. Ovyn, X. Rouby, and V. Lemaitre, arXiv:hep-ph/0903.2225v3 (2010).

[4] G. Aad *et al.* (ATLAS Collaboration), arXiv:0901.0512v4 (2009).