Search for $t\bar{t}H$ in multilepton final states at the ATLAS experiment

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On behalf of the ATLAS Collaboration
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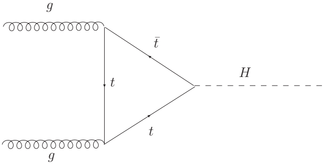
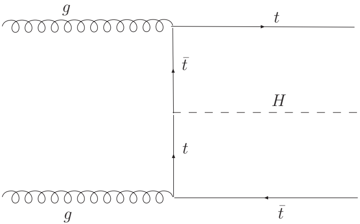
Motivation for looking for $t\bar{t}H$

- Measurement of Yukawa coupling of Higgs to fermions important probe for New Physics
- Coupling indirectly observed through production of Higgs by gluon-gluon fusion and through Higgs decay in photon pair
- The goal is to do a direct measurement of this coupling at the tree level only possible at the LHC via $t\bar{t}H$ and tH



- Gluon-gluon fusion production



- $t\bar{t}H$ production

$t\bar{t}H$ Multileptons

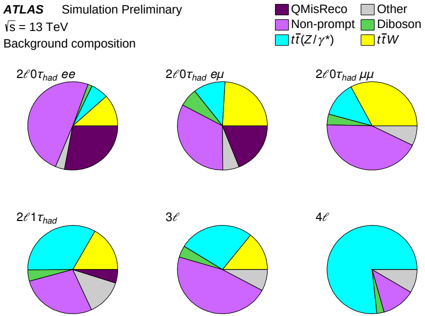
	Higgs boson decay mode			
Category	WW^*	$\tau\tau$	ZZ^*	Other
$2\ell SS0\tau_{had}$	77%	17%	3%	3%
$2\ell SS1\tau_{had}$	46%	51%	2%	1%
3ℓ	74%	20%	4%	2%
4ℓ	72%	18%	9%	2%

conf note: ATLAS-CONF-2016-058

- Decays of Higgs to WW, $\tau\tau$ mainly targeted
- Four channels considered for analysis at 13.2 fb^{-1}
  - Two same-charge leptons with 0 hadronic tau ($2\ell 0\tau_{had}$: $e^{\pm}e^{\pm}$, $e^{\pm}\mu^{\pm}$, $\mu^{\pm}\mu^{\pm}$)
  - Three leptons (3ℓ)
  - Two same-charge leptons with 1 hadronic tau ($2\ell 1\tau_{had}$)
  - Four leptons (4ℓ)

Jets and lepton p_T selection in signal region			
$2\ell 0\tau_{had}$	$2\ell 1\tau_{had}$	3ℓ	4ℓ
$\geq$ 1bjets & $\geq$ 5jets	$\geq$ 1bjets & $\geq$ 4jets	$\geq$ 1bjets & $\geq$ 4jets or $\geq$ 2bjets & $=$ 3jets	$\geq$ 1bjets & $\geq$ 2jets
$> 25 GeV$	Leading ℓ $p_T > 25 GeV$ Subleading ℓ $p_T > 15 GeV$	Same-Sign ℓ $p_T > 20 GeV$ Third ℓ $p_T > 10 GeV$	$> 10 GeV$

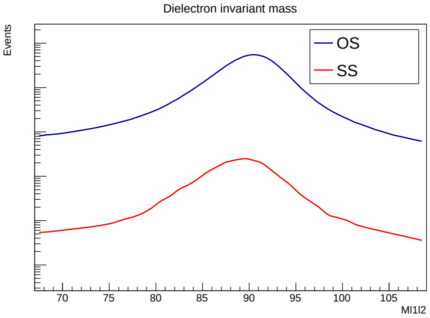
Background processes



- Irreducible backgrounds (prompt light leptons)
  - $t\bar{t}Z$, $t\bar{t}W$, VV
  - Rare backgrounds: $t\bar{t}WW$, tH, tZ, $t\bar{t}t\bar{t}$, WtZ
  - MC simulation used with addition of theoretical uncertainties
- Reducible backgrounds (data-driven) originating from $t\bar{t}$, single top processes
  - Non-prompt/fakes leptons
  - For 2ℓSame-Sign channels: electron charge flip (QMisId)

QMisId estimation in 2ℓSS channels: Likelihood method

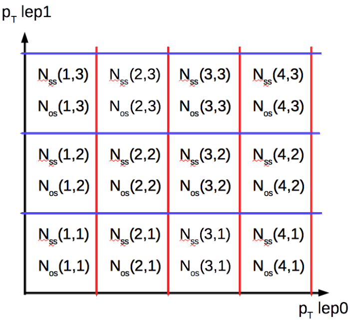
- Z(ee) events used for rates extraction
- ϵ_i rate of charge MisId for a single electron in region i (in η, p_T, E ...)
- For N_{tot} $e^{\pm}e^{\pm}$ events: $N_{ss} = N_{tot}[(1-\epsilon_i)\epsilon_j + (1-\epsilon_j)\epsilon_i] \simeq N_{tot}(\epsilon_i + \epsilon_j)$
- Probability to produce a charge mis-identification from two electrons is $P(N^{ij}(\epsilon_i + \epsilon_j)|N^{ij}_{SS})$
- Likelihood maximisation of $\prod_{i,j} P(N^{ij}(\epsilon_i + \epsilon_j)|N^{ij}_{SS})$ used to extract ϵ



- Rates then applied to OS events with same selection as our signal region (only reversal of SS leptons condition)
  $N_{ss} = N_{OS}[\frac{\epsilon_i+\epsilon_j}{(1-\epsilon_j-\epsilon_i)}]$

QMisId estimation in 2ℓSS channels: Binning

- Estimation of QMisId done in 2D: based on eta and pt for electron passing tight requirements
  - Choices of variables and ranges to cover impact of material (η) and curvature of electron track (p_T)
  - Simultaneous extraction of the rates in the 2D (no factorization)
- Rates in last p_T bin extrapolated from [90;130] GeV bin using $t\bar{t}$ MC → to cope with limited statistics



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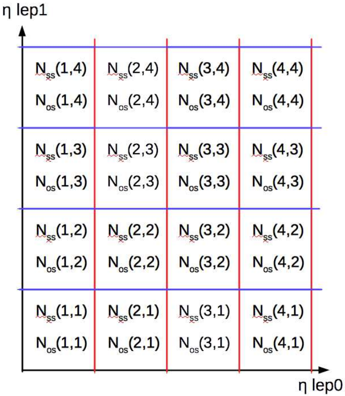
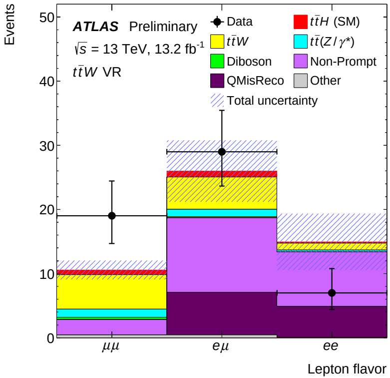


QMisid estimation: results

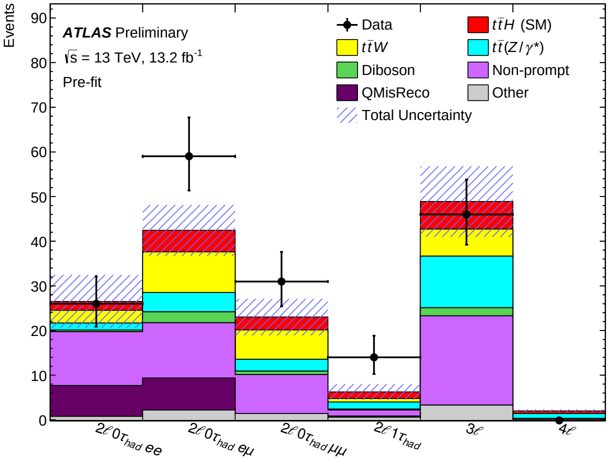
- Rates varying from 2×10^{-4} at small η and p_T to 10^{-1} at high η and p_T
- Closure test done looking at $e^{\pm}e^{\pm}$ events with at least 1b-jet and $m_{ee} - m_Z$<10GeV → good agreement between prediction and observation
- Total uncertainty on QMisId at the order of 15%
  - Mainly coming from statistics in the bins used for rates extraction



- Yields (contribution in % to the background yield) in the signal region:
  - $N^{ee}_{QMisId}(5j) = 6.9 \pm 1.3$ (28%),
  - $N^{e\mu}_{QMisId}(5j) = 7.1 \pm 1.7$ (19%),
  - $N^{2l1\tau}_{QMisId}(4j) = 0.24 \pm 0.03$ (5%)

Combined fit in $t\bar{t}H$ multilepton channel: Events in SR

- Cut and count analysis
- Non-prompt leptons and QMisId estimated with data-driven method



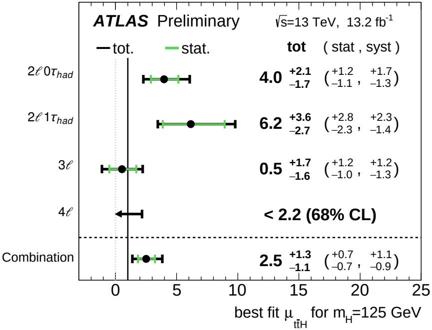
Systematic uncertainties

- Dominant systematics $\rightarrow$
  - From data-driven non-prompt background estimation
  - Jet Vertex Tracker (proba. for jets to be associated to right vertex)
  - Theoretical uncertainties on $t\bar{t}V$ and $t\bar{t}H$

Uncertainty Source	$\Delta\mu$	
Non-prompt leptons and charge misreconstruction	$+0.56$	-0.64
Jet-vertex association, pileup modeling	$+0.48$	-0.36
$t\bar{t}W$ modelling	$+0.29$	-0.31
$t\bar{t}H$ modelling	$+0.31$	-0.15
Jet energy scale and resolution	$+0.22$	-0.18
$t\bar{t}Z$ modelling	$+0.19$	-0.19
Luminosity	$+0.19$	-0.15
Diboson modelling	$+0.15$	-0.14
Jet flavor tagging	$+0.15$	-0.12
Light lepton (e, μ) and τ_{had} ID, isolation, trigger	$+0.12$	-0.10
Other background modeling	$+0.11$	-0.11
Total systematic uncertainty	$+1.1$	-0.9

Fit Results

- The final result combines the sensitivity obtained in all $t\bar{t}H$ multilepton channels



- Significance observed (expected): 2.2σ (1.0σ)
- Significance w.r.t $t\bar{t}H$ SM prediction: 1.3σ
- Exclusion limit observed (expected): 4.9 (2.3) times the Standard Model

Conclusion

- Presentation of $t\bar{t}H$ multilepton analysis with $13.2fb^{-1}$done
- Focus on QMisId estimate in $2\ell SS$ channels
  - Contribute in signal region with electrons up to 28% of the background yield
  - Uncertainties on this background estimated to be around 15%
- Global fit of ttH to multilepton analysis presented
- Final result of $\mu = 2.5^{+1.3}_{-1.1}$ with an observed (expected) significance of 2.2σ (1σ)

Backup

Selection for all channels

SR/VR	Channel	Selection criteria
SR	$2\ell SS0\tau_{had}$	Two tight light leptons with $p_T > 25, 25$ GeV
		Sum of light lepton charges ± 2
		Any electrons must have $\lvert\eta_e\rvert < 1.37$
		Zero τ_{had} candidates
		$njets \geq 5$ and $nbjets \geq 1$
SR	$2\ell SS1\tau_{had}$	Two tight light leptons, with $p_T > 25, 15$ GeV
		Sum of light lepton charges ± 2
		Exactly one τ_{had} candidate, of opposite charge to the light leptons
		$\lvert m(ee) - 91.2\ \mathrm{GeV}\rvert > 10$ GeV for *ee* events
		$njets \geq 4$ and $nbjets \geq 1$
SR	3ℓ	Three light leptons; sum of light lepton charges ± 1
		Two same-charge leptons must be tight and have $p_T > 20$ GeV
		$m(\ell^+\ell^-) > 12$ GeV and $\lvert m(\ell^+\ell^-) - 91.2\ \mathrm{GeV}\rvert > 10$ GeV for all SFOC pairs
		$\lvert m(3\ell) - 91.2\ \mathrm{GeV}\rvert > 10$ GeV
		$njets \geq 4$ and $nbjets \geq 1$, or $njets = 3$ and $nbjets \geq 2$
SR	4ℓ	Four light leptons; sum of light lepton charges 0
		All leptons pass "gradient" isolation selection
		$m(\ell^+\ell^-) > 12$ GeV and $\lvert m(\ell^+\ell^-) - 91.2\ \mathrm{GeV}\rvert > 10$ GeV for all SFOC pairs
		$100\ \mathrm{GeV} < m(4\ell) < 350$ GeV and $\lvert m(4\ell) - 125\ \mathrm{GeV}\rvert > 5$ GeV
		$njets \geq 2$ and $nbjets \geq 1$

Comments on QMisid

- QMisId on muons negligible
  - Could only originate from bad track curvature reonstruction
  - Limited by long lever arm between inner detector and muon spectrometre
- QMisId in other channels
  - In 3ℓ channel could only contribute from events with 3 leptons of same-sign $\rightarrow$ very few such events
    - For events with 2 leptons SS and 1 OS the effect of QMisId would only be to lose events going to 3SS leptons.If one of the 2SS see a charge flip it will still be a 2SS+1OS lepton events (only total charge inverted)

Yields in SR

	$2\ell 0\tau$ ee	$2\ell 0\tau$ $e\mu$	$2\ell 0\tau$ $\mu\mu$	$2\ell 1\tau$	3ℓ	4ℓ
$t\bar{t}W$	2.9 ± 0.7	9.1 ± 2.5	6.6 ± 1.6	0.8 ± 0.4	6.1 ± 1.3	—
$t\bar{t}(Z/\gamma^*)$	1.55 ± 0.29	4.3 ± 0.9	2.6 ± 0.6	1.6 ± 0.4	11.5 ± 2.0	1.12 ± 0.20
Diboson	0.38 ± 0.25	2.5 ± 1.4	0.8 ± 0.5	0.20 ± 0.15	1.8 ± 1.0	0.04 ± 0.04
Non-prompt leptons	12 ± 6	12 ± 5	8.7 ± 3.4	1.3 ± 1.2	20 ± 6	0.18 ± 0.10
Charge misreconstruction	6.9 ± 1.3	7.1 ± 1.7	—	0.24 ± 0.03	—	—
Other	0.81 ± 0.22	2.2 ± 0.6	1.4 ± 0.4	0.63 ± 0.15	3.3 ± 0.8	0.12 ± 0.05
Total background	25 ± 6	38 ± 6	20 ± 4	4.8 ± 1.4	43 ± 7	1.46 ± 0.25
$t\bar{t}H$ (SM)	2.0 ± 0.5	4.8 ± 1.0	2.9 ± 0.6	1.43 ± 0.31	6.2 ± 1.1	0.59 ± 0.10
Data	26	59	31	14	46	0