Measurement of $H \rightarrow \tau \tau$ in the $\tau_{lep} + \tau_{had}$ final state using the ATLAS detector

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In the SM, $H \rightarrow \tau\tau$ is currently the only accessible decay at LHC to establish Higgs-Yukawa coupling to leptons.
• Cut-based analysis using 2015+2016 datasets collected at $\sqrt{s} = 13$ TeV
  • Multivariate analysis ongoing in parallel to increase final sensitivity

• Harmonisation across different channels to use similar signal regions and similar object definitions

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<th>lep-lep</th>
<th>lep-had</th>
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</table>
| **VBF region**   | $p_T^{lead.jet} > 40$ GeV ($70$ GeV for had-had), $p_T^{sublead.jet} > 30$ GeV  
$\Delta \eta$ (jets) > 3 in opp. hemisphere, $M$ (jets) > 400 GeV |
| **Boosted region** | Fail VBF region, $p_T^H > 100$ GeV |

• Combined fit on the di-tau mass ($MMC$) based on Maximum Likelihood Estimation ($MLE$) to determine the signal strength

$$\mu = \frac{\sigma \times BR}{(\sigma \times BR)_{SM}}$$
Event selection for the $\tau_{lep} + \tau_{had}$ final state

- Preselection cuts:
  - Trigger: Single Lepton Trigger (SLT) + Tau Lepton Trigger (TLT) combination
  - Lepton features:
    - Isolation requirement
    - Good reconstruction quality (medium ID)
    - $p_T > 14.7$ GeV (muon), $18$ GeV (electron)
  - Hadronic tau features:
    - Good reconstruction quality (medium ID)
    - $|\eta| < 2.4$, $|q| = 1$, $p_T > 20$ GeV
  - Opposite sign between lepton and hadronic tau
  - No b-jets
  - $M_T(lep, MET) < 70$ GeV

- Control region (CR) definitions:
  - QCD CR: invert cut on lep. isolation
  - W CR: invert cut on $M_T(lep, MET)$
  - Top CR: invert cut on b-jets and $M_T(lep, MET) > 40$ GeV
Fake estimation

- Possible sources of fakes for mis-reconstructed electrons or muons (leptonic side):
  - no data driven strategy at the moment to estimate this low contribution

- Possible sources of fakes for mis-reconstructed hadronic taus (hadronic side)
  - Contribution from electrons strongly reduced using:
    - Geometrical overlap removal (ORL)
    - Electron Likelihood rejection (LLH)
    - Electron BDT rejection
  
  - Contribution from jets estimated using two techniques:
    - OS-SS method (backup)
    - Fake Factor method (default)
**Fake Factor method**

- **Data driven technique**

- Consider events where a tau is faked by a jet; invert tau ID (anti-tau)

\[
N_{\text{jet} \rightarrow \tau} = (N_{\text{fail,SR}}^{\text{Data}} - N_{\text{fail,SR}}^{\text{MC,nojet} \rightarrow \tau}) \times FF_{SR}
\]

- *Fakes* normalisation is obtained from the transfer factor (\(FF_{SR}\)) from anti-tau region to signal region

- Shape of *Fakes* are taken from anti-tau region in Data
Overall, good Data/MC modelling for key-variables in the analysis
Signal regions for cut-based analysis

- VBF region
  - $p_T^{lead\,jet} > 40$ GeV
  - $p_T^{sublead\,jet} > 30$ GeV
  - $\Delta\eta$ (jets) > 3, opposite hemisphere
  - Jets visible mass ($M_{jj}$) > 400 GeV
  - $\min(\eta^{jet}) < \eta^{lep/tau}$ and $\max(\eta^{jet}) > \eta^{lep/tau}$
  - $MET > 20$ GeV
  - $\Delta R(l, \tau) < 3$ and $\Delta \eta(l, \tau) < 1.5$

- Split in *Loose* and *Tight* regions based on $M_{jj}$

- Boosted region:
  - Fail VBF region requirements
  - $p_T^H > 100$ GeV
  - $MET > 20$ GeV
  - tau $p_T > 30$ GeV
  - $\Delta R(l, \tau) < 2.5$ and $\Delta \eta(l, \tau) < 1.5$

- Split in *High* and *Low* regions based on $p_T^H$
Detector level plots in signal regions

- Splitting in sub-regions will increase significance in the fit
Fit model for the $\tau_{lep} + \tau_{had}$ final state

- **Boosted (VBF) Top CR**: region defined using Boost (VBF) selection and inverting cut on b-jets and $M_T(\text{lep}, \text{MET}) > 40$ GeV
- **Boosted (VBF) Z CR**: region defined using $Z \rightarrow ll$ + low MET events and Boost (VBF) selection
- Used to get normalisation in signal regions
Analysis in ongoing to perform cross-section measurement for $H \to \tau \tau$ in Run 2 using 2015+2016 dataset

Precision measurements like Higgs differential cross-section and Higgs decay properties will follow after having established the cross section measurement
Thanks For Your Attention
Backup
Run 1 coupling measurement results

- Run1 paper: JHEP04(2015)117

- Split in VBF and Boosted categories to enrich VBF and ggH topologies, respectively

- Analysis used both BDT and cut-based (CB) approach

- Focus on BDT result due to better performance
  - Observed (Expected) significance: 4.5 (3.4) $\sigma$
Systematic errors

- Systematics are coming from different used object:
  - muons: identification, reconstruction, tracks association
  - electrons: identification, detector effects (temperature, etc.)
  - taus: energy scale, identification
  - jets: energy scale, b-tagging, resolution
  - MET: resolution, energy scale

- Both kinematic and weight systematics are taken into account for the final fit

- In total more than 150 systematic variation

Elec Eff. ID syst. for $Z \rightarrow \tau\tau$ process

Tau Eff. ID syst. for $Z \rightarrow \tau\tau$ process