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$H \to \tau\tau$ coupling measurement in the lepton-hadron final state using the ATLAS detector

Antonio De Maria
Supervised by: Arnulf Quadt

II. Physikalisches Institut

Special thanks to all the $H \to \tau\tau \to$ lep-had analysis team

Terascale meeting, DESY
Higgs session

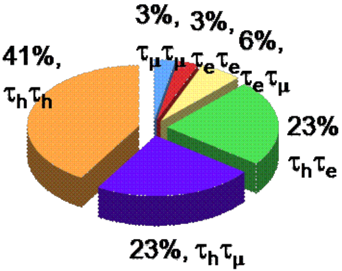
Bundesministerium
für Bildung
und Forschung

BMBF-Forschungsschwerpunkt
ATLAS-EXPERIMENT
Physik bei höchsten Energien mit dem ATLAS-Experiment am LHC

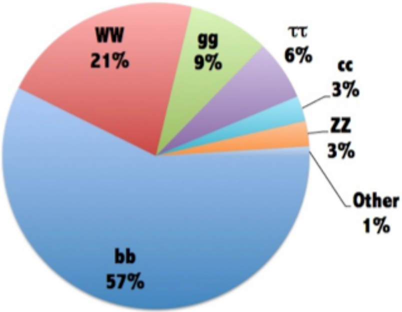
FSP 103
ATLAS

$H \to \tau\tau$ search motivation

- In the SM, $H \to \tau\tau$ is currently the only accessible decay at LHC to establish Higgs-Yukawa coupling to leptons



$H \to \tau\tau$ decay modes



Higgs decay modes

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWG

Run 2 coupling measurement

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- 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

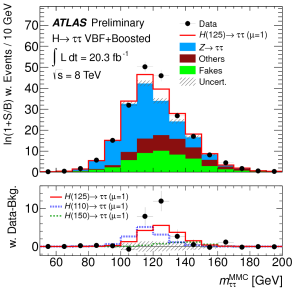
	lep-lep lep-had had-had
VBF region	$p_T^{lead.jet} > 40$ GeV (70 GeV for had-had), $p_T^{sublead.jet} > 30$ GeV
	$\Delta\eta$ (jets) > 3 in opp. hemisphere, M (jets) > 400 GeV
Boosted region	Fail VBF region, $p_T^H > 100$ GeV

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

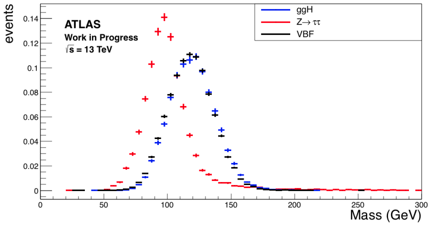
$$\mu = \frac{\sigma \times BR}{(\sigma \times BR)_{SM}}$$

Introduction to *MMC*

- Reconstruction of the mass of a resonance decaying into a pair of tau leptons is difficult because of the neutrinos in final state
- *Missing Mass Calculator* (*MMC*):
  - The orientations of the neutrinos and other decay products must be consistent with the mass and decay kinematics
  - Result is achieved by minimising a likelihood in the kinematically allowed phase space region (`http://arxiv.org/pdf/1012.4686.pdf`)
- Succesfully used in Run1, but it needs and re-tuned for Run2 due to ATLAS detector upgrades



ATLAS-CONF-2013-108



Re-tuned MMC in the Boosted region

Event selection for the $\tau_{lep} + \tau_{had}$ final state

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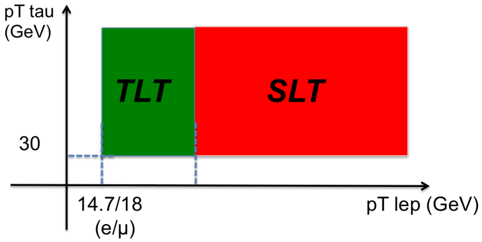
- Preselection cuts:
  - Trigger: Single Lepton Trigger (SLT) + Tau Lepton Trigger (TLT) combination
  - Lepton features:
    - Gradient isolation
    - medium ID quality
    - $p_T > 14.7$ GeV (muon), 18 GeV (electron)
  - Hadronic tau features:
    - medium ID quality
    - $|\eta| < 2.4$, $|q| = 1$, $p_T > 30$ GeV
  - Opposite sign between lepton and hadronic tau
  - No b-jets
  - $M_T(lep, MET) < 70$ GeV
  - $MET > 20$ GeV



Trigger scheme

- 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

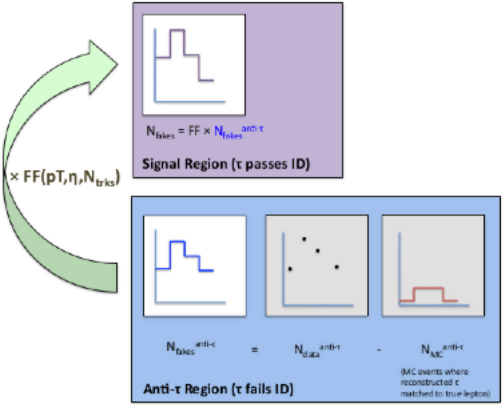
- Possible sources of fakes for mis-reconstructed electrons or muons (leptonic side):
  - no data driven strategy at the moment to estimate this low contribution

- 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

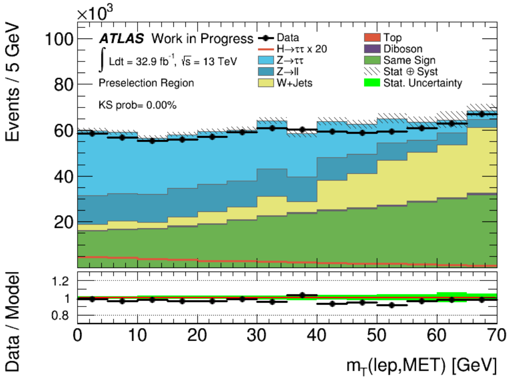
  - Contribution from jets estimated using two techniques:
    - OS-SS method (backup)
    - Fake Factor method (default)

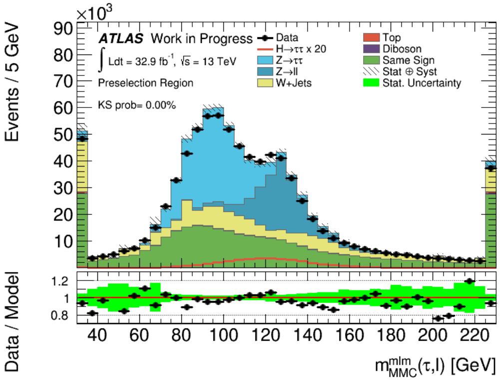
Fake Factor method

- Data driven technique
- Consider events where a tau is faked by a jet; invert tau ID (anti-tau)
- $N_{jet\to\tau} = (N^{fail,SR}_{Data} - N^{fail,SR}_{MC,nojet\to\tau}) * FF_{SR}$
- *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



Detector level plots at pre-selection

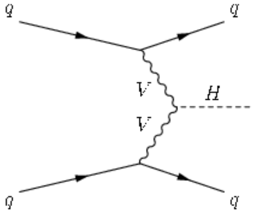




- Overall, good Data/MC modelling for key-variables in the analysis

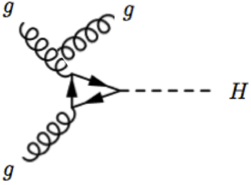
Signal regions for cut-based analysis

- 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}



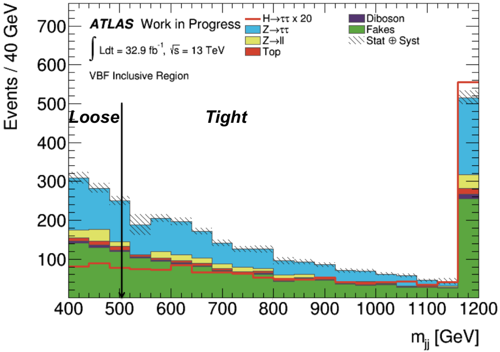
VBF Higgs production

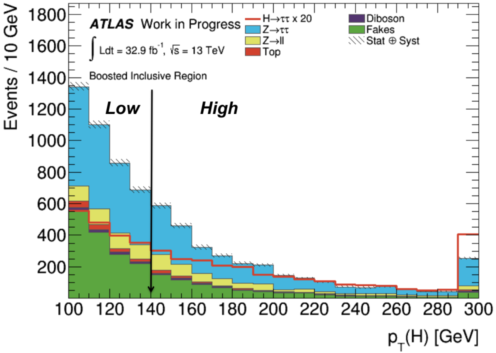
- Boosted region:
  - Fail VBF region requirements
  - $p_T^H > 100$ GeV
  - $MET > 20$ GeV
  - tau $p_T > 30$ GeV
  - $\Delta R(l, \tau) < 2.5$ and $\Delta\eta(l, \tau) < 1.5$
- Split in *High* and *Low* regions based on p_T^H



ggF (+ 1 jet) Higgs production

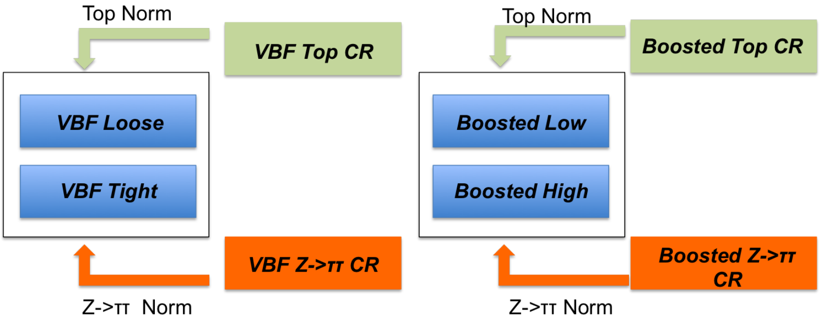
Detector level plots in signal regions





- Splitting in sub-regions will increase significance in the fit

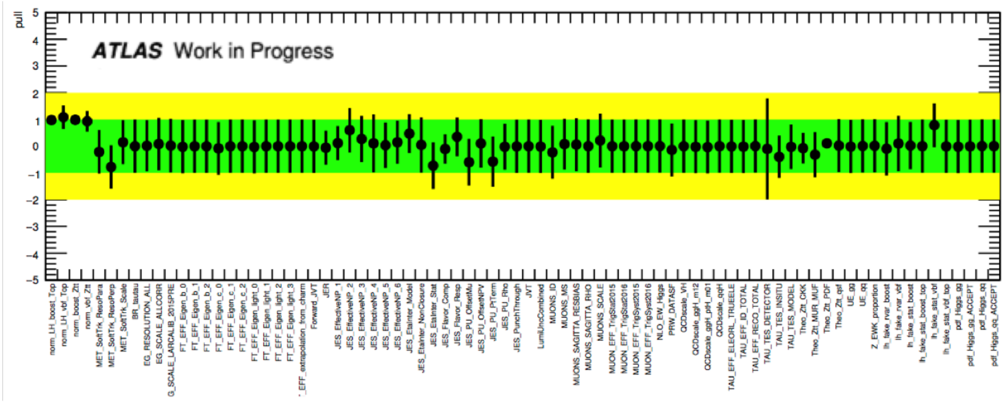
Fit model for the $\tau_{lep} + \tau_{had}$ final state



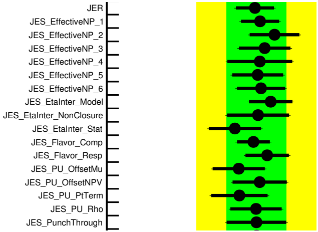
- Boosted (VBF) Top CR : region defined using Boost (VBF) selection and inverting cut on b-jets and $M_T(lep, MET) > 40$ GeV
- Boosted (VBF) Z CR: region defined using $Z \rightarrow ll$ + low MET events and Boost (VBF) selection
- Used to get normalisation in signal regions

The JER/JES fit problems for $m^{\mathrm{MMC}} < 100$ GeV

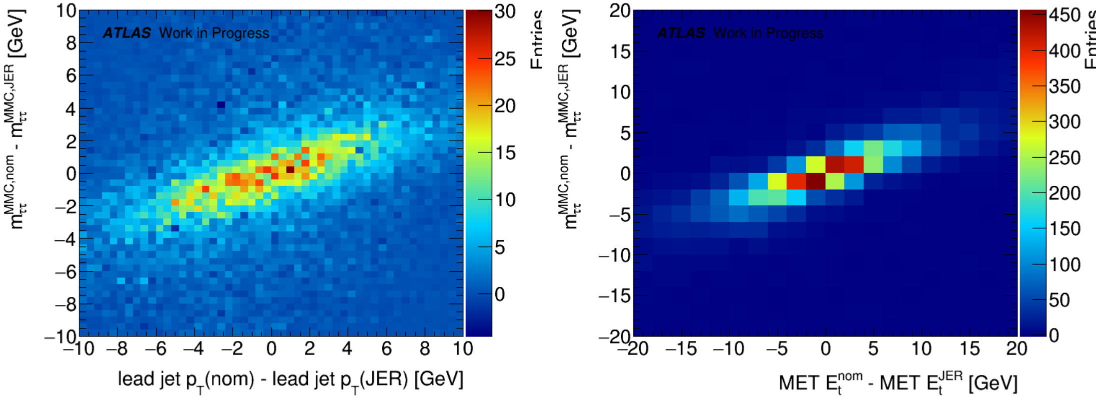
Unblinded!



- Results from fit in a side band region (Z peak)
- Strong constraints for all JER and JES NPs
- Comes from acceptance effects (cuts on $E_{\mathrm{T}}^{\mathrm{miss}}$ and jet p_{T}) as well as directly from the MMC calculation



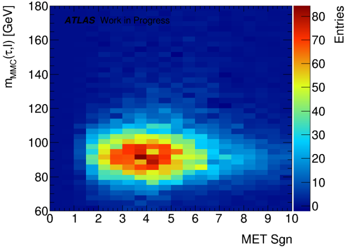
Understanding the JER effect on MMC



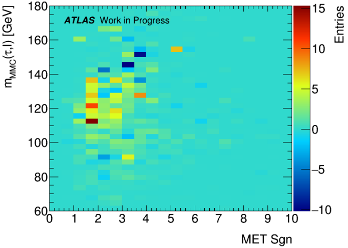
- Shift in E_{T}^{miss} and p_{T,jet_0} from JER variation translates directly into shift in m^{MMC}
    - Shift of the Z peak (high stat region) is causing NP constraint

Future improvement: MET significance

- MMC vs MET Sign plots



$Z \to \tau\tau$



$Z \to ll$

Sample	No MET Sgn cut	MET Sgn > 2	Eff. (%)
Zll	244.08 ± 35.10	138.77 ± 31.67	57
Ztt	7861.29 ± 71.91	7453.08 ± 70.02	95
ggH	131.97 ± 2.14	125.63 ± 2.07	95

- Reduction of 40 % of $Z \to ll$ background in the blinded region, while no impact on the signal

Summary and outlook

- Analysis in ongoing to perform cross-section measurement for $H \rightarrow \tau\tau$ in Run 2 using 2015+2016 dataset

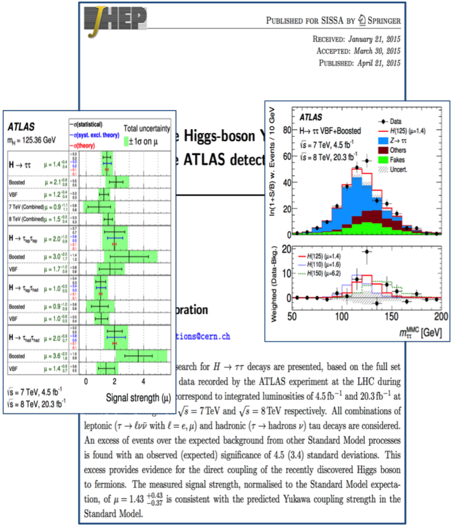
- Precision measurements like Higgs differential cross-section and Higgs decay properties will follow after having established the cross section measurement

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) σ



Fake Factor calculation

- Assumptions:
  - All background processed (except QCD) can be described using W fake-factors
  - 2015 and 2016 datasets can be combined
  - Fake-factors calculated in different CRs can be used in SR

$$FF_i = \frac{N_{data}^{pass,CR-i} - N_{MC,not\ j\to\tau}^{pass,CR-i}}{N_{Data}^{fail,CR-i} - N_{MC,not\ j\to\tau}^{fail,CR-i}}$$

$$R_W = 1 - R_{QCD}$$

$$FF = R_W FF_W + R_{QCD} FF_{QCD}$$

$$N_{QCD,data}^{anti-\tau} = (N_{Data}^{QCDCR,anti-\tau} - N_{MC,true\ lepton}^{QCDCR,anti-\tau}) \cdot IF$$

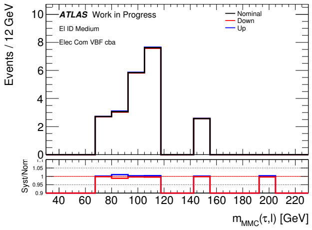
$$R_{QCD} = \frac{N_{QCD,data}^{anti-\tau}}{N_{Data}^{anti-\tau} - N_{MC,not\ j\to\tau}^{anti-\tau}}$$

$$IF = \frac{N_{data}^{iso,SSP} - N_{MC,true\ lepton}^{iso,SSP}}{N_{Data}^{non-iso,SSP} - N_{MC,true\ lepton}^{non-iso,SSP}}.$$

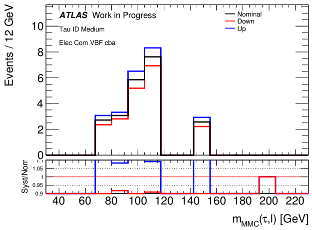
- pure MC fake validation studies have also been performed as further cross-check

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 $Z \to \tau\tau$ process



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