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$H \to \tau\tau$ searches in lep-had final state using Run2 data in the ATLAS experiment

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

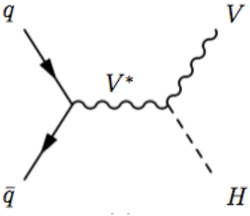
Terascale meeting, DESY
Higgs session

Bundesministerium für Bildung und Forschung

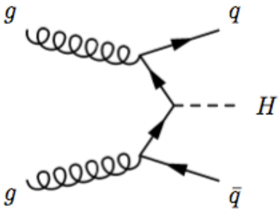
FSP 101 ATLAS

PHYSICS AT THE TERA SCALE Helmholtz Alliance

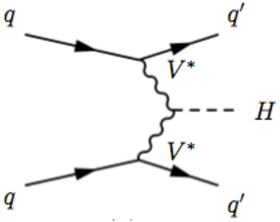
Higgs Production mode at LHC



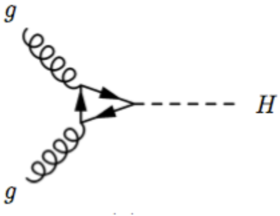
Associated production with a vector boson (VH)



Associated production with Top quarks (ttH)



Vector-Boson Fusion (VBF)



Gluon-gluon fusion (ggH)

$H \to \tau\tau$ search motivation

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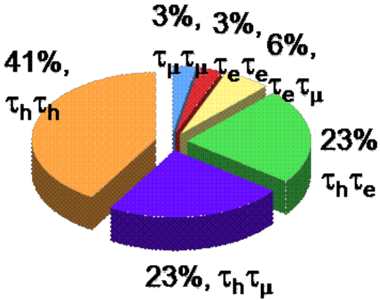
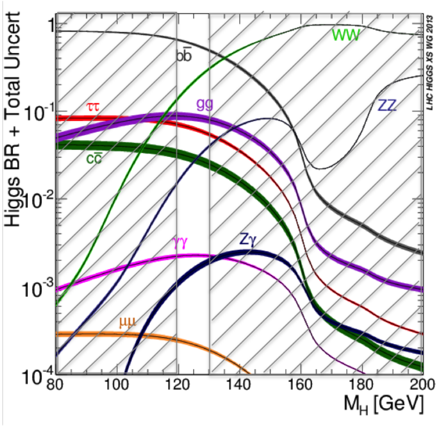
- In the SM, $H \to \tau\tau$ is the only currently accessible decay at LHC to establish Higgs-Yukawa coupling to leptons
- $H \to \tau\tau$ better S/B then $H \to bb$, so establishes Yukawa coupling to fermions



$H \to \tau\tau$ decay modes



Higgs Branching Ratio as function of mass

Run1 coupling measurement results

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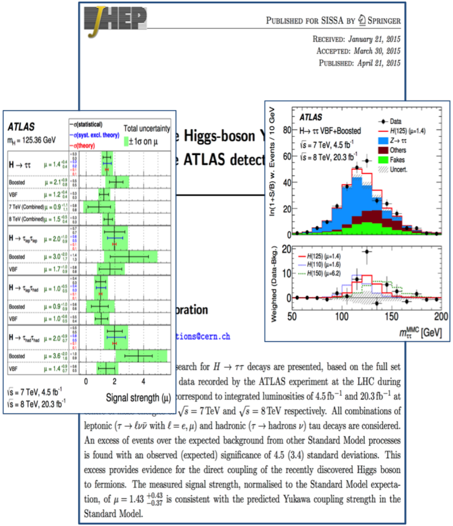
- Run1 paper: JHEP04(2015)117
- Split in VBF and Boosted categories to enrich VBF and ggH topologies, respectively
- Analysis used both BDT and cut-based (CB) approach
- Focus on BDT result due to better performance
  - Observed (Expected) significance: 4.5 (3.4) σ



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2013-108/

Run2 coupling measurement

- Cut-based analysis only using data collected at $\sqrt{s}$= 13 TeV
- Harmonisation across different channels to use similar VBF and Boosted categories
- Embedding still to be finished in Run2
  - $Z \rightarrow \tau\tau$ modelled with simulation (MadGraph5+Pythia8 generator)
  - EW V+jets production (VBF-like) simulated using Sherpa 2.1
- No Higgs mass scan, only $M_H = 125$ GeV, simulated with Powheg+Pythia generator

Event Selection

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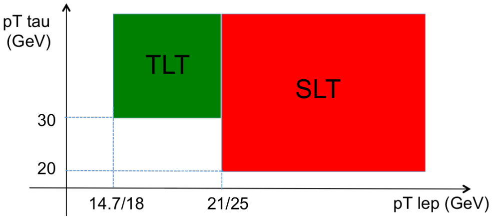
- Preselection cuts:
  - Trigger: Single Lepton Trigger (SLT) + Tau Lepton Trigger (TLT) combination
  - Lepton requirements:
    - Gradient Isolation
    - Medium quality
    - $p_T > 14.7$ GeV (muon), 18 GeV (electron)
  - Tau Requirements:
    - Medium quality
    - $|\eta| < 2.4$, $|q| = 1$, $p_T > 20$ GeV
  - Opposite Sign
  - No b-jets
  - Transverse Mass (lep, MET) < 70 GeV



Trigger scheme

- Control Region (CR) definitions:
  - Zll CR: two same-flavor, opposite sign leptons
  - QCD CR: invert cut on lep. isolation
  - W CR: invert cut on transverse mass
  - Top CR: invert cut on b-jets and transverse Mass (lep, MET) > 40 GeV

Fake Estimation

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

- Possible sources of fakes for hadronic taus (hadronic side)
  - Contribution from electrons strongly reduced using:
    - Geometrical overlap removal (ORL)
    - Electron Likelihood rejection (LLH)

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

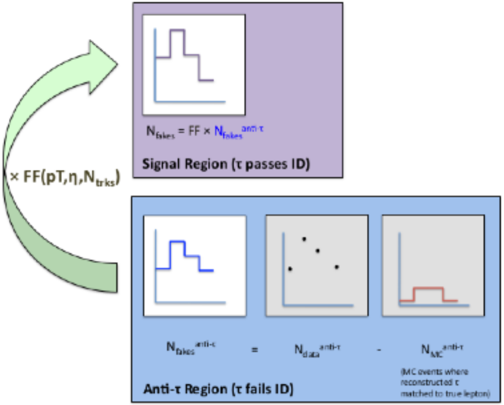
Fake Factor method

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

$$N_{jet\to\tau} = (N^{fail,SR}_{Data} - N^{fail,SR}_{MC,nojet\to\tau}) * FF_{SR}$$

  where FF is the transfer factor from anti-tau region to signal region

- Rate and shape of *Fakes* are taken from anti-tau region in Data
- Anti-tau region: cut on jet BDT score to get q/g jet fraction comparable to signal region



Plots at Preselection

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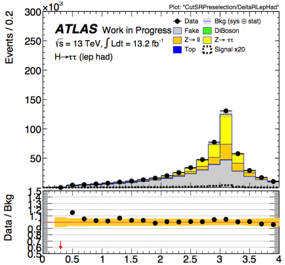
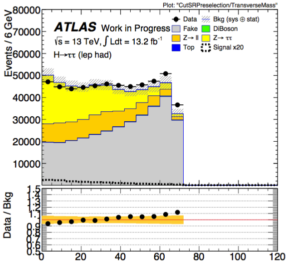
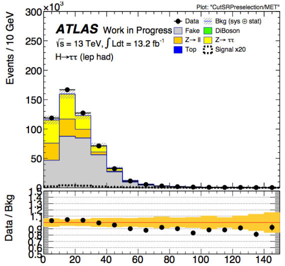


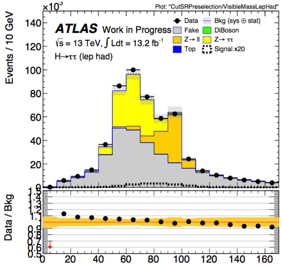
ΔR(τ,lep) dist.



m_T (lep,MET) dist. (GeV)



MET dist. (GeV)



$m^{\tau\tau}$vis dist. (GeV)

Signal Regions def. for CB analysis

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- VBF region cut based
  - $p_T^{lead.jet} > 40$ GeV
  - $p_T^{sublead.jet} > 30$ GeV
  - $\Delta\eta$ (jets) > 3, opposite hemisphere
  - Jets visible mass > 300 GeV
  - min $\eta^{jet} < \eta^{lep/tau}$ and max $\eta^{jet} > \eta^{lep/tau}$ (centrality)
  - $MET > 20$ GeV
  - $\Delta R(l,\tau) < 3$
  - $\Delta\eta(l,\tau) < 1.5$
- Further split in:
  - VBF Tight:
    - Jets visible mass > 500 GeV
    - $p_T^H > 100$ GeV
    - $p^\tau > 30$ GeV
    - $m_{vis}^{\tau\tau} > 40$ GeV
  - VBF Loose
    - Fail VBF Tight requirement

- Boosted region cut based:
  - Fail VBF region requirements
  - $p_T^H > 100$ GeV
  - $MET > 20$ GeV
  - tau $p_T > 30$ GeV
  - $\Delta R(l,\tau) < 2.5$
  - $\Delta\eta(l,\tau) < 1.5$
- Further split in:
  - Boost High Hpt:
    - $p_T^H > 140$ GeV
    - $\Delta R(l,\tau) < 1.5$
  - Boosted Low Hpt:
    - Fail Boosted High Hpt requirement

Plots for VBF Incl. Top CR

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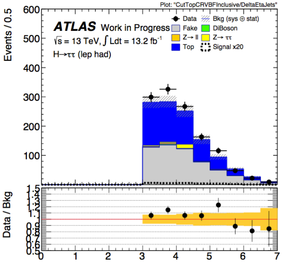
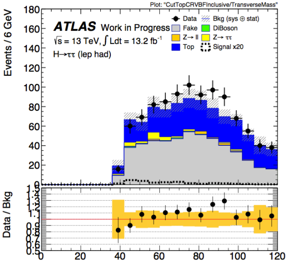
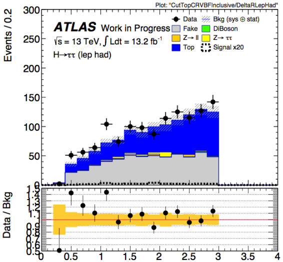


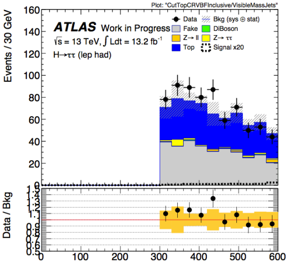
$\Delta\eta_{jj}$ dist.



m_T (lep,MET) dist. (GeV)



$\Delta R(\tau$,lep) dist.



m_{jj} *dist.(GeV)*

Plots for Boosted Incl. Top CR

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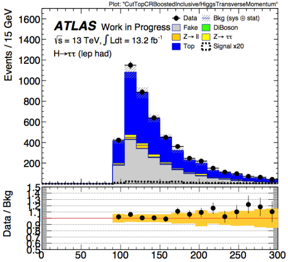
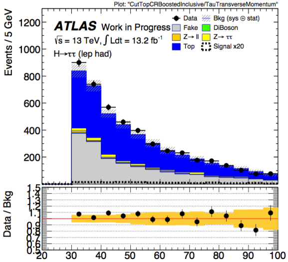
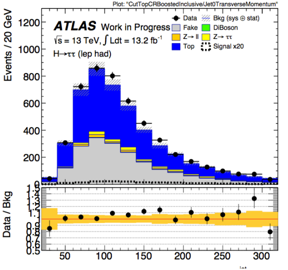


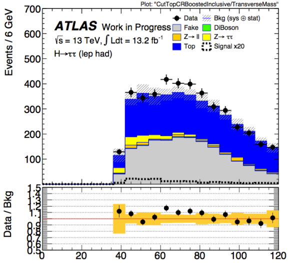
$p^H{}_T dist.(GeV)$



tau $p_T dist.(GeV)$



lead. jet $p_T dist.(GeV)$



m_T (lep,MET) dist. (GeV)

Systematic Errors

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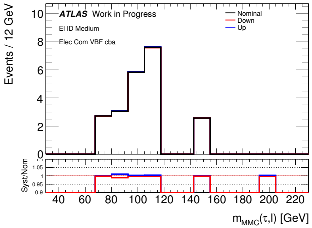
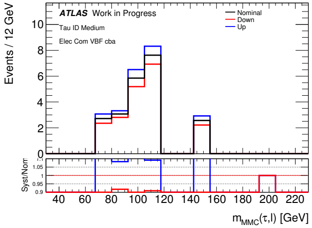
- Systematics are coming from different used object:
  - muons: identification, reconstruction, tracks association
  - electrons: identification, detector effects (temperature, etc.)
  - taus: energy scale, identification
  - jets: energy scale, b-tagging, resolution
  - MET: resolution, energy scale
- Both kinematic and weight systematics are taken into account for the final fit
- In total more than 150 systematic variation

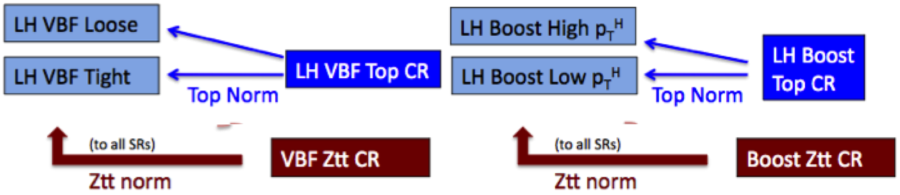


Elec Eff. ID syst. for $Z \to \tau\tau$ process



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

Fit Model for the lep-had ch.



- 1 bin in Top CR to get normalisation in Signal Regions
- 1 bin in $Z \to \tau\tau$ CR ($Z \to ll$ + low MET events) to get normalisation in Signal Regions

Summary

- Analysis chain for Lep-had channel is now quite stable but still opened to improvements
  - many analysis tools have been built from scratch due to many changes in ATLAS respect to Run 1
- Harmonisation across different channels to use centralised object selection and similar Signal Regions
- Fitting model and diagnostic fit tools have been also adapted to new Run2 analysis

Thanks For Your Attention

Backup

VBF production mode features

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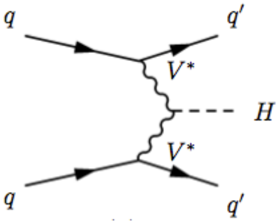

Vector-Boson Fusion (VBF)

$\sqrt{s}$ (TeV)	cross section (pb) *
8	1.578
13	3.748

- cross section $\simeq$ 12 times less than ggH, but clearer experimental signature

- Suppressed color exchange between quark lines give rise to:
  - Little jet activity in central rapidity region
  - Scattered quarks -> two forward tagging jets (energetic; large rapidity gap)
  - Higgs decay products tipically between tagging jets

* https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections