SM and heavy Higgs bosons decaying to τ pairs

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VII CPAN days

http://atlas.ch

Run: 189280
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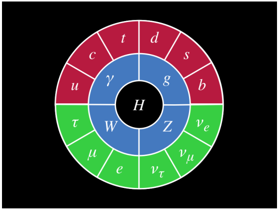
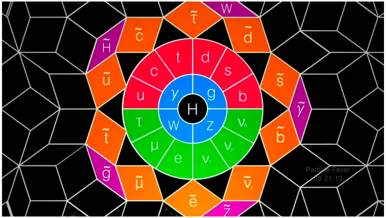
Outline

Introduction

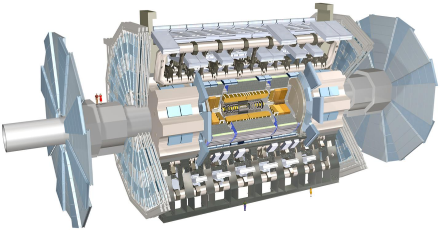
- Higgs boson is the Standard Model of Particle Physics' last missing piece
- $> 5\sigma$ evidence in both bosonic and fermionic decays
- $H \to \tau^+\tau^-$ is a key channel both for the SM prediction of the fermionic coupling and for further searches of a BSM Higgs boson
- MSSM model directly favours $\tau\tau$ channel by enhancing its coupling, and can be observed through three predicted bosons $(h,\ H,\ A)$

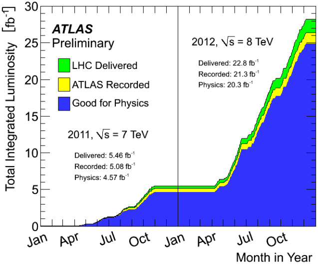




ATLAS detector

- ATLAS is a general-purpose detector located in one of the collision points of the LHC at CERN.
- Working from 2011 collecting data from *pp* collisions
- Integrated luminosity good for physics collected in Run I:
  - 2011: $4.5fb^{-1}$ at 7 TeV c.m.e
  - 2012: $20.3fb^{-1}$ at 8 TeV c.m.e
- Integrated luminosity good for physics collected in Run II:
  - 2015: $3.3fb^{-1}$ at 13 TeV c.m.e
- Analyses reviewed includes all data from Run I (2011 and 2012)

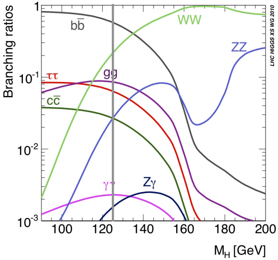


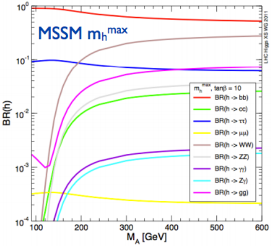


Data collected in Run I

Topology of the process $H \to \tau\tau$

- Branching ratio of $H \to \tau\tau \sim 6.7\%$
- Less BR than $H \to b\bar{b}$ but much easier detection due to a better S/B ratio
- SM:
  - Main production mode is Gluon Gluon Fusion (ggH)
  - Vector Boson Fusion (VBF) and Vector Associated Production (VH) are relevant.
  - VBF has a clear signature (two energetic jets) that makes it the most significant signal source
- MSSM:
  - Coupling of vector bosons to the Higgs particle is suppressed w.r.t SM
  - *b*-associated production is enhanced, which makes bbH and ggH the two main signal production sources.





Outline

Analysis of SM $H \to \tau\tau$

Final States:

- Full Leptonic ($\tau_{\to lep}\tau_{\to lep}$)
- Semi leptonic ($\tau_{\to lep}\tau_{\to had}$)
- Full hadronic ($\tau_{\to had}\tau_{\to had}$)

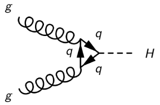
Analysis techniques

- MVA (7+8 TeV): Main analysis
- CutBased (8 TeV): Cross check

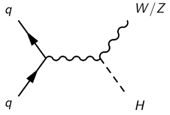
Background models

- $Z \to \tau\tau$ (Irreducible)
- $Z \to ll$ ($l = \mu, e$)
- W+jets,top, di-boson
- $H \to W^+W^-$
- Fake leptons

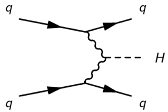
Signal models H125



ggH $\sim$ 87%



VH $\sim$ 5%



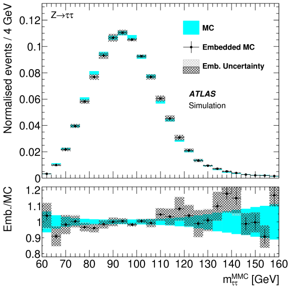
VBF $\sim$ 7%

Analysis categories:

- VBF (at least two jets)
- Boosted (high $p_T^{\tau\tau}$)

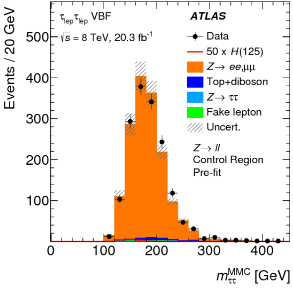
Background modelling

$Z\tau\tau$ background, irreducible



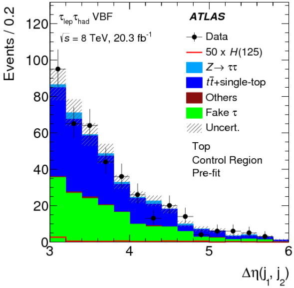
Comparsion MC/Embedding for $Z\tau\tau$

Zll controlled in Z peak region



MMC in LepLep Zll CR

Top controlled in b-tagged region



$\Delta\eta_{jj}$ in LepHad TopCR

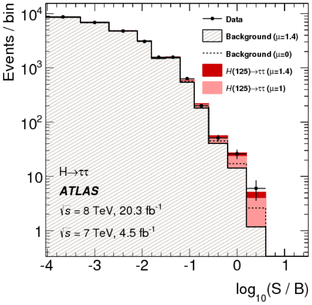
Estimation of backgrounds via data-driven techniques when possible: $Z\tau\tau$ via embedding of τ particles in a $Z \to \mu\mu$ data sample

Fakes are estimated via Template Fit in LepLep and HadHad, and via Fake Factor in LepHad

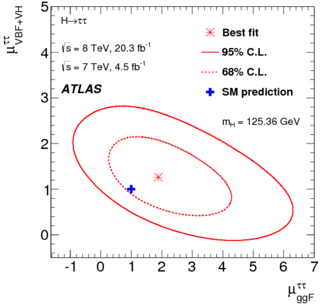
Rest of backgrounds are estimated using MC models, validated in dedicated control regions (Top, Zll).

Results MVA: Combined $H \to \tau\tau$

Combination result of all categories, in all final states for 7 and 8 TeV



Event yields as a function of log(S/B)



Likelihood contours showing compatibility with SM

Excess with a statistical significance of 4.5σ (expected for H125: 3.3σ)

$$\mu \equiv \sigma/\sigma_{SM} = 1.43^{+0.27}_{-0.26}\ (\text{stat})\ {}^{+0.32}_{-0.24}\ (\text{syst})\ \pm 0.09\ (\text{theo.})$$

CMS Result: $\mu = 0.78 \pm 0.27$ at 3.2σ (3.7σ expected)

Outline

Analysis of heavy MSSM $H \to \tau\tau$

Similar analysis compared to the SM one. Most of the backgrounds and techniques are shared, as well as final states.

The main difference is the range of search, not centered in 125GeV but extended the whole range 150-1000 GeV. In order to improve the significance, the different categories and cuts have been optimized for a specific range.

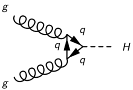
Final States:

- Fully leptonic ($\tau_{\to lep}\tau_{\to lep}$)
- Semi leptonic ($\tau_{\to lep}\tau_{\to had}$)
- Fully hadronic ($\tau_{\to had}\tau_{\to had}$)

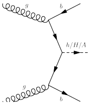
Background models

- $Z \to \tau\tau$ (Irreducible)
- $Z \to ll$ ($l = \mu, e$)
- W+jets, top, di-boson
- Fake leptons

Signal models for masses 300-1000 GeV



ggH



bbH

Analysis categories:

- b-veto / b-tag (LepHad, LepLep)
- High-mass (LepHad)
- Single-Tau/Di-Tau Trigger (HadHad)

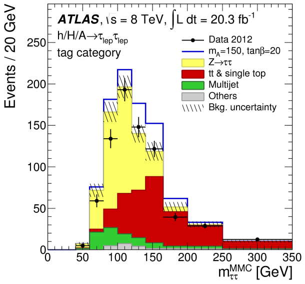
Results

Two observables depending of the category:

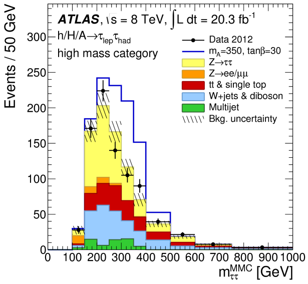
Invariant mass MMC, used for LepLep and LepHad channels

m_T^{Tot} is the total sum of the transverse mass of the event, used in HadHad channels.

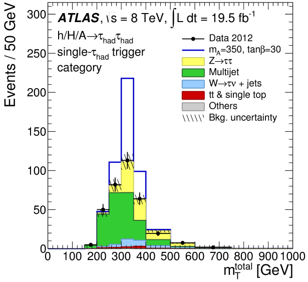
$$m_T^{Tot} = \sqrt{m_T^2\left(\tau_1, \tau_2\right) + m_T^2\left(\tau_1, E_T^{Miss}\right) + m_T^2\left(\tau_2, E_T^{Miss}\right)}$$



MMC in LepLep b-tag category



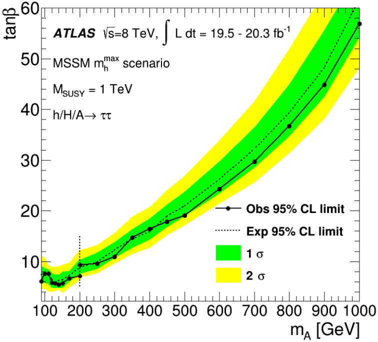
MMC in LepHad high mass category



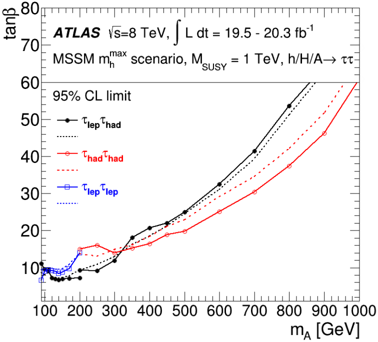
m_T^{Tot} in HadHad Single Tau Trigger cat

Limits

Combining all the categories and performing the signal extraction we can obtain some exclusion plots:



Exclusion limits on $\tan\beta$ as a function of m_A



Exclusion limits separated by channels

Setting values we could summarize that values of $\tan\beta > 5.4$ are excluded for a $m_H = 140 GeV$ (low mass) while in the high mass region we can exclude values of $\tan\beta > 37$ are excluded for a $m_H = 800 GeV$

Outline

Summary

- Results from theses analysis improve our understanding of the fermionic couplings of the Higgs Boson
- In the SM, we can claim evidence of the $\tau\tau$ decay:
  - ATLAS Results: $\mu = 1.43^{+0.43}_{-0.37}$ at 4.5σ (3.3σ expected)
  - The combination of ATLAS and CMS gives a significance of 5.5σ
- Hence, we can can claim solid evidence of the coupling of Higgs boson to fermions, while no excess w.r.t. SM has been found

- In the MSSM sector, the analysis has been performed looking for traces of a heavier Higgs boson in the range 150-1000 GeV
- The study has allowed us to set exclusion limits on the $tan\beta$ and m_A parameters
- The results are still compatible with the SM with the current precision, and so, no hints of New Physics has been observed yet, but this analysis will have a key role in the Run II of LHC

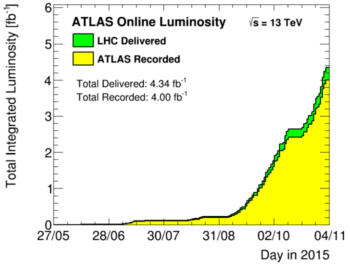
- Both analysis were published in JHEP:
  - SM (April 2015): `http://link.springer.com/article/10.1007/JHEP04%282015%29117`
  - MSSM (November 2014): `http://link.springer.com/article/10.1007/JHEP11(2014)056`

Prospects for Run II

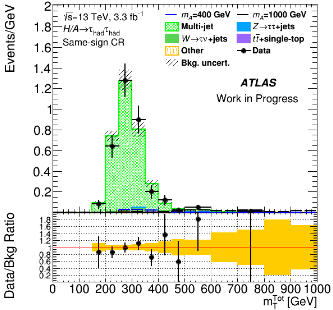
LHC was restarted in June and ATLAS has been able to collect enough statistics at 13TeV to allow us resume the analysis. In particular we have reached the $3.3 fb^{-1}$ of good for physics data.

Although the beginning has been slow, we are at the doors of confirm New Physics beyond the Standard Model

All the groups are working hard to develop the first analysis using the new data.



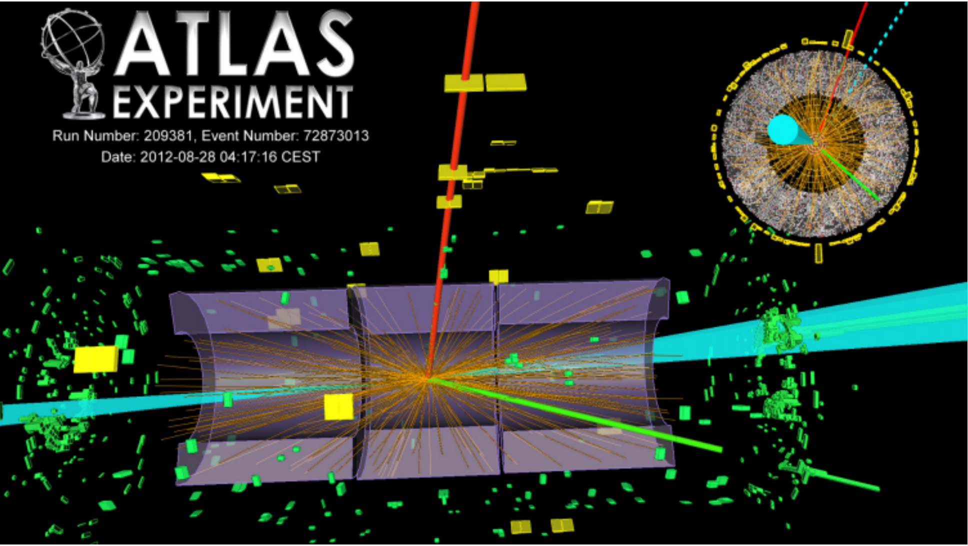
Integrated Luminosity collected in ATLAS in 2015 proton physics



Total Transverse mass in the HadHad SS Control Region after the cutflow

Event candidate of a $H \to \tau_\mu \tau_e$ decay

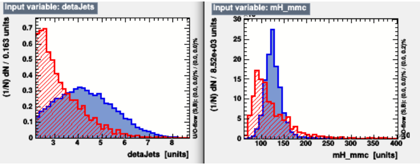
Thanks for your attention!



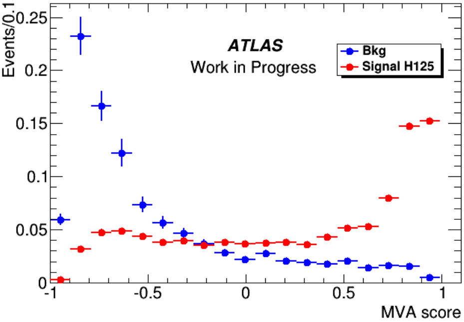
BACKUP

MVA Technique

- MultiVariate Analysis (using BDT)
- Uses information from different dynamical variables to discriminate signal from background
- Output is a value (BDT Score) which can be interpreted as the likelihood of an event of being signal-like (or background-like)
- Before apply it on data, it has to be trained on a MC model of our expected distributions.



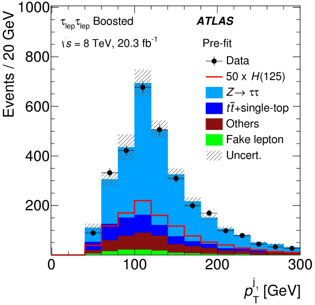
Discrimination power of two input variables



Normalized shape of BDT output for MC

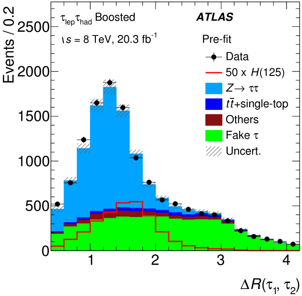
Example variables before the BDT for the three subchannels. The distribution of the different backgrounds can be observed

LepLep



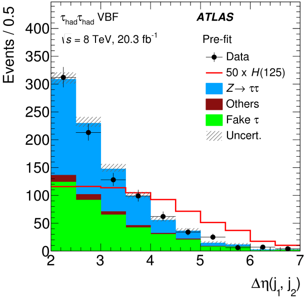
Leading Jet p_T in VBF $H \rightarrow \tau_{lep}\tau_{lep}$

LepHad



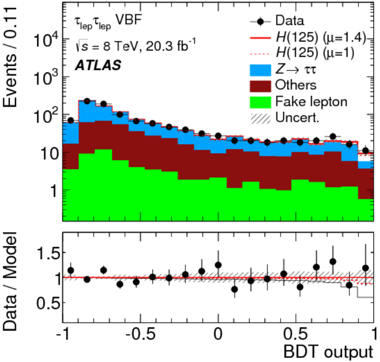
$\Delta R(\tau_1\tau_2)$ in Boosted $H \rightarrow \tau_{lep}\tau_{had}$

HadHad

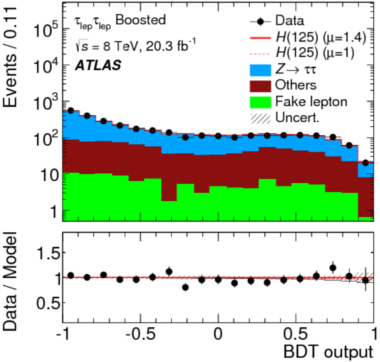


$\Delta\eta(j_1 j_2)$ in VBF $H \rightarrow \tau_{had}\tau_{had}$

Results LepLep 8 TeV



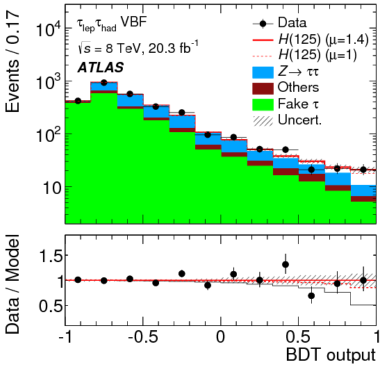
BDT discriminant at 8 TeV for VBF category in $H \rightarrow \tau_{lep}\tau_{lep}$



BDT discriminant at 8 TeV for Boosted category in $H \rightarrow \tau_{lep}\tau_{lep}$

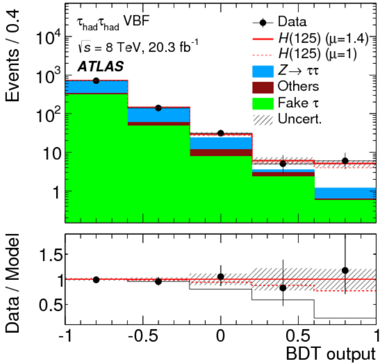
Results 8 TeV VBF cat

LepHad



BDT discriminant at 8 TeV for VBF category in $H \to \tau_{lep}\tau_{had}$

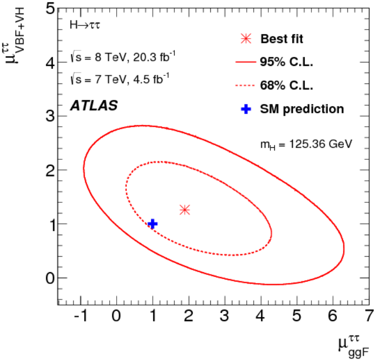
HadHad



BDT discriminant at 8 TeV for VBF category in $H \to \tau_{had}\tau_{had}$

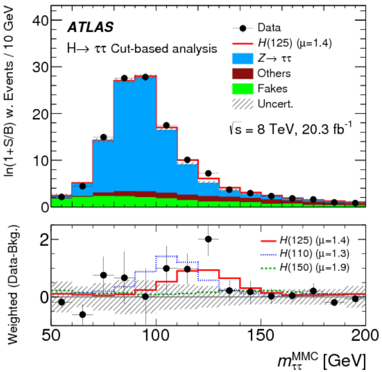
Results MVA: Compatibility with SM

$$\mu^{\tau\tau}_{ggH} = 2.0 \pm 0.8 \text{ (stat) } {}^{+1.2}_{-0.8} \text{ (syst) } \pm 0.3 \text{ (theo.)}$$
$$\mu^{\tau\tau}_{VBF+VH} = 1.24^{+0.49}_{-0.45} \text{ (stat) } {}^{+0.31}_{-0.29} \text{ (syst) } \pm 0.08 \text{ (theo.)}$$

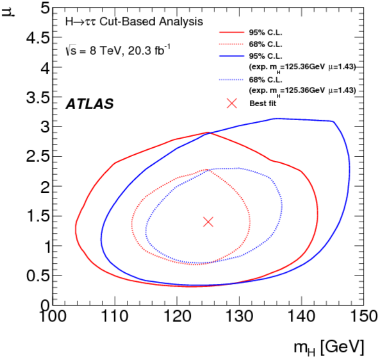


Likelihood contours showing compatibility with SM

Results Cut-Based: Combined $H \to \tau\tau$



Reweighted MMC plot for the combined $H \to \tau\tau$



Likelihood contours of CBA showing 68% and 95% C.L. for $\mu = 1$ (red) and $mu = 1.4$ (blue)

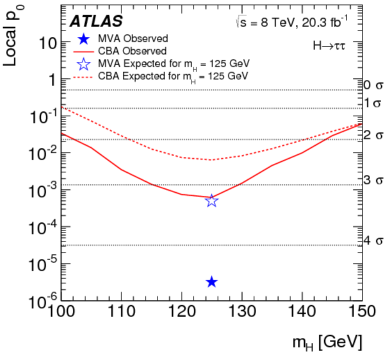
Excess with a statistical significance of 3.2σ (expected 2.5σ at H125) with

$$\mu = 1.43^{+0.36}_{-0.35}\ \text{(stat)}\ ^{+0.41}_{-0.33}\ \text{(syst)} \pm 0.10\ \text{(theo.)}$$

Results MVA vs Cut-Based

$$\mu_{MVA} = 1.43^{+0.43}_{-0.37} \text{ at } 4.5\sigma \text{ of significance } (3.3\sigma \text{ exp})$$

$$\mu_{CBA} = 1.43^{+0.55}_{-0.49} \text{ at } 3.2\sigma \text{ of significance } (2.5\sigma \text{ exp})$$



$p0$ as a funcion of m_H for CBA and MVA, both expected and observed values are shown.

Systematics NP plot