Search of a high mass neutral Higgs boson in fermion final states with the ATLAS detector.

Gaetano Αθανάσιος Barone

*Brandeis University*

On behalf of the ATLAS collaboration

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Heavy neutral Higgs bosons predicted by several Standard Model extensions, in particular

- Minimal super symmetric Standard Model (MSSM)
- Two Higgs doublet model (2HDM)
  - CP even neutral doublet \((h, H)\) and CP odd pseudo scalar \(A\) and two scalars \(H^\pm\)
  - motivated also by dark matter axion models

Present recent searches for high mass neutral Higgs boson in fermion final states with the ATLAS detector

1. \(A/H \rightarrow t\bar{t}\)
2. \(A/H \rightarrow \tau\bar{\tau}\)
$A/H \rightarrow t\bar{t}$
Decays of $A/H$ to $t\bar{t}$ enhanced for $\tan\beta<3$ and $m_{A/H}>500$ GeV.

- Parameter region not probed by previous searches.

- Significant interference between $gg\to t\bar{t}$ production and $A/H\to t\bar{t}$
  - for $m_{A/H}$ above $t\bar{t}$ threshold, for LHC $t\bar{t}$ main production
  - Resonant shape distorted to a peak-dip structure.
A/H → tt̅

- Analysis in the lepton (ℓ) plus jets (j) final state
  - One lepton (e or μ) with $p_T(\ell) > 25$ GeV.
  - At least four anti-$k_T(4)$ jets with $p_T(j) > 25$ GeV.
  - $E_{T\text{miss}} > 20$ GeV and $E_{T\text{miss}} + m_T W > 60$ GeV.

- Considering only resolved kinematics
  - Most efficient strategy for $m_{A/H} < 800$ GeV

- Event classification into six categories
  - Kinematic $\chi^2$ for jet association to W

- W+jets and Multijet contributions estimated from data.

- Leading uncertainties
  - Jet modelling $\sim6\%$ on B and $\sim9\%$ on S+I
  - tt̅ modelling $\sim7\%$ ($m_t$ and pdf)
\[ \mu \cdot S + \sqrt{\mu} \cdot I + B = \sqrt{\mu} \cdot (S + I) + (\mu - \sqrt{\mu}) \cdot S + B. \]

- **CL_s limits taking into account signal (S), background (B) and interference (I)**
  - \( \tan\beta < 0.7 \) for \( m_A=550 \text{ GeV} \) and \( \tan\beta < 0.72 \) for \( m_H=550 \text{ GeV} \)
- **First and strictest limits in this this parameter region**

More details in Katharina Behr's poster and Saverio D’Auria's talk

G. Barone
$A/H \rightarrow \tau\bar{\tau}$
For large $\tan\beta$ $A/H$ couplings to leptons and down quarks enhanced.

- Increased branching fractions to $\tau$-leptons

- Dominant production modes:
  - gluon gluon fusion for low $\tan\beta$,
  - $b$-associated production for high $\tan\beta$

Events are split into two categories:

- $b$-tag veto category: no $b$-jets in production.
- $N(b$-jets)$ > 0$ associated $b$-jet production.
A/H → ττ

**T reconstruction and event selection**

- Two τ decay modes are considered:
  - All hadronic final state (τ_{had}τ_{had}).
  - Semileptonic final state (τ_{lep}τ_{had}).

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<td>(</td>
<td>\Delta \varphi(ℓ, τ_{had})</td>
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<td>( m_T(ℓ, E_T^{miss}) &lt; 40 ) GeV</td>
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**Dominant backgrounds estimated from data**

- Estimate rates of jets faking taus by inverting identification criteria

\[
 f(\mathbf{x}) \equiv \frac{N_{\text{pass}}^{\text{data}}(\mathbf{x}) - N_{\text{bkg}}^{\text{pass}}(\mathbf{x})}{N_{\text{fail}}^{\text{data}}(\mathbf{x}) - N_{\text{bkg}}^{\text{fail}}(\mathbf{x})}
\]

- from regions in data enhancing the Mulitjet background, tt̅ and W+jets
Reconstruction of $\tau\tau$ final states.

- Two $\tau$ decay modes are considered:
  - All hadronic final state ($\tau_{\text{had}}\tau_{\text{had}}$) both $\tau$ decay hadronically.
  - Semileptonic final state ($\tau_{\text{lep}}\tau_{\text{had}}$) one $\tau$ decays hadronically and one leptonically.

- Discriminant is total transverse mass:

$$m_T^{\text{tot}} \equiv \sqrt{(p_T^{\tau_1} + p_T^{\tau_2} + E_T^{\text{miss}})^2 - (p_T^{\tau_1} + p_T^{\tau_2} + E_T^{\text{miss}})^2}$$

- Missing energy challenges $m_{\tau\tau}$
- Backgrounds larger component in longitudinal axis.
● Results from profile likelihood fit on transverse mass $m_{T^{\text{tot}}}$

● Model independent limits on $\sigma \times BR (H/A)$ production
  ‣ Separately for $ggF$ production and $b$-associated production.
  ‣ Limits from 200 GeV to > 2.0 TeV on $m_\phi$
  ‣ Narrow-width assumption of $\phi$
Results interpreted as limits on MSSM and hMSSM models

- For hMSSM $\tan\beta > 1.0$ for $m_A=0.25$ TeV and $\tan\beta > 45$ for $m_A=1$ TeV excluded.
- For $m_{h^{\text{mod+}}}$ $\tan\beta > 5.3$ for $m_A=0.25$ TeV and $\tan\beta > 54$ for $m_A=1$ TeV excluded.

Presence of low mass neutralinos decrease $A/H \rightarrow \tau\tau$ branching fraction.

More details of the $Z' \rightarrow \tau\tau$ limits in Giacomo Artoni’s talk.
Conclusions
Conclusion

• ATLAS has good sensitivity to standard models extensions

• Searches for new phenomena involving heavy neutral scalar production
  ‣ Decaying into quarks ($t$) and leptons ($\tau$)

• Carried novel experimental techniques to constrain the background.
  ‣ Multivariate $\tau$ identification, background suppression.

• Model independent limits
  ‣ Interpretations on MSSM limits also given.
Additional material
### T reconstruction and event selection

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- Hadronic $\tau$ decays: one or more charged particles, a neutrino and $\pi^0$
- Visible decay products identification based on multivariate technique
- 50% to 60% identification efficiencies measured on $Z \rightarrow \tau\tau$

![Graph showing inverse background efficiency vs. signal efficiency](image1)

![Graph showing events vs. $m_{\text{vis}}(\mu, \tau_{\text{had}})$](image2)
• Hadronic tau decays: one or more charged particles, a neutrino and $\pi^0$

• Visible decay products ID based on multivariate technique

  ‣ Rejection of jets faking a tau lepton.
  ✦ Shower shapes and track multiplicities.

  ‣ 50% to 60% identification efficiencies measured on $Z \rightarrow \tau\tau$

ATLAS Simulation
Tau Particle Flow
Diagonal fraction: 74.7%

$3h > 1\pi^0$

$3h ≥ 2\pi^0$

$3h ≥ 3\pi^0$

Reconstructed decay mode

Generated decay mode

$Z/\gamma^* \rightarrow \tau\tau$

ATLAS Simulation

$Z/\gamma^* \rightarrow \tau\tau$

Events

12000

10000

8000

6000

4000

2000

0

1 - background efficiency

0.5

0.5

1

ATLAS Preliminary

Data 2016

$Z \rightarrow \tau\tau \rightarrow \mu^+\mu^-$

Other

Stat. Unc.

$\int L dt = 7.1 \text{ fb}^{-1}$

$\sqrt{s} = 13 \text{ TeV}$

Visible Mass ($\tau, \mu$) [GeV]

0

0.5

1

40

50

60

70

80

90

100

110

120

Data exp.

1.5

2

$E_\text{Tmiss} \tau$ leptonic decays stringent requirements

G. Barone

August-17
- Results from profile likelihood fit on transverse mass $m_T^{\text{tot}}$