Searching for BSM Higgs and Gauge Bosons Decaying to Two Tau Leptons Using 36 fb$^{-1}$ of Data Collected at $\sqrt{s}=13$ TeV with the ATLAS Detector

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on behalf of ATLAS

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motivation

- many BSM scenarios have an extended Higgs sector
  - Two-Higgs-Doublet Models (2HDMs) predict 5 Higgs bosons
    - Type-II 2HDM corresponds to Higgs sector of the Minimal Supersymmetric Model

- one of several extra Higgs searches at ATLAS

- Z' bosons can arise from extensions of electroweak symmetry
  - sequential standard model
  - non-universal G(221) model
production and decay

- separate by resonance production mode:
  - Higgs $b$-associated production $\rightarrow b$-tag category
  - Higgs gluon-gluon fusion $\rightarrow b$-veto category
  - $Z'$ Drell-Yan production $\rightarrow$ inclusive category

- separate by tau decay mode
  - lep-had and had-had channels
  - skip lep-lep - very little improvement in sensitivity
**event selection**

**lep-had**

- single-lepton trigger (40-120 GeV depending on data-taking period)
- leptonic tau:
  - matched to trigger
  - isolation criteria
- hadronic tau:
  - medium ID (BDT score)
  - $p_T > 25$ GeV and $|\eta| < 2.7$

  $m_T(\text{lep, MET}) = \sqrt{2p_T^{\text{lep}} \cdot \text{MET}(1 - \cos \Delta \phi(\text{lep, MET}))} < 40$ GeV

- 80 < $m_{\text{vis}}$ < 110 GeV veto for e-had

**had-had**

- single-tau trigger (80, 125, 160 GeV depending on data-taking period)
- leading tau:
  - matched to trigger
  - $p_T > \text{trigger } p_T + 5$ GeV
  - medium ID (BDT score)
- subleading tau:
  - $p_T > 65$ GeV
  - loose ID (BDT score)
**backgrounds: had-had**

- Monte Carlo with data-driven jet→τ fake rates:
  - Drell-Yan Z/γ*→ττ (two real taus)
  - W→τν+jets (one real tau, one fake tau)
  - single top quark, ttbar
  - diboson
  - W→lν+jets
  - Z→ll+jets

- data-driven method:
  - QCD multijet (jet→τ fakes)
backgrounds: lep-had

- Monte Carlo:
  - Drell-Yan $Z/gamma^* \rightarrow ll, tau tau$
  - top quark, ttbar
  - diboson
  (true lepton and either true tau or lepton $\rightarrow$ tau fake)

- data-driven method:
  - QCD multijet (lepton and tau faked by jets)
  - W+jets (true lepton, jet $\rightarrow$ tau fake; b-veto category)
  - ttbar (true lepton, jet $\rightarrow$ tau fake; b-tag category)
data-driven background estimation for had-had

\[ N_{QCD}^{SR} = MJ-FF \times (N_{CR1}^{data} - N_{CR1}^{non-MJ}) \]

- fake factors are binned in subleading tau pT
data-driven background estimation for lep-had

→ multijet fake factors are binned in leptonic tau pT
→ W+jets/tt fake factors are binned in hadronic tau pT
systematic uncertainties

- for Monte Carlo:
  - theoretical cross-section calculation
  - luminosity, pile-up uncertainty
  - efficiency of reconstruction, identification, triggering algorithms
  - energy scale and resolution of e, μ, τ, (b-)jets, MET

- for data-driven background estimates:
  - fake factors: limited size of fake regions, background subtraction
fit model

- parameter of interest: signal strength

\[ \mu = \frac{(\sigma \times BR)_{\text{observed}}}{(\sigma \times BR)_{\text{predicted}}} \]

- final discriminant:

\[ m_T^{\text{tot}} = \sqrt{m_T^2(\tau_1, \tau_2) + m_T^2(\text{MET}, \tau_1) + m_T^2(\text{MET}, \tau_2)} \]

- fit function: likelihood function constructed as the product of Poisson probability terms (one for each bin in \( m_T^{\text{tot}} \))

- simultaneous fit in (lep-had, had-had) x (b-veto, b-tag) \( m_T^{\text{tot}} \) histograms
post-fit plots

lep-had b-veto

lep-had b-tag

had-had b-veto

had-had b-tag
model-independent limits

- Higgs gluon-gluon fusion
- Higgs b-associated production
- Z' Drell-Yan
MSSM interpretations

**ATLAS**

\[ \sqrt{s} = 13 \text{ TeV}, \ 36.1 \text{ fb}^{-1} \]

MSSM \( m_{h}^{\text{mod+}} \) scenario, \( M_{\text{SUSY}} = 1 \text{ TeV} \)

\[ H/A \rightarrow \tau \tau \ 95\% \text{ CL limits} \]

\[ m_{A} \text{ [GeV]} \]

\[ \tan \beta \]

**ATLAS** Preliminary

hMSSM, 95% CL limits

- Observed
- Expected

\[ m_{A} \text{ [GeV]} \]

**September 2019**
Z' interpretation

non-universal G(221) model
Summary and future results

- 2015+2016 data, results published in JHEP
- no new resonance found, but new limits set
- currently getting ready to publish results with full Run 2 (2015-2018) data, following the same analysis strategy
- next: Run 2 legacy paper with improvements
backup
Limits by channel

\[ \sigma \times B(\phi \to \tau \tau) \, [\text{pb}] \]

\[ m_\phi \, [\text{GeV}] \]

\[ \sqrt{s} = 13 \text{ TeV}, \, 36.1 \text{ fb}^{-1} \]

\[ \phi \to \tau \tau \, 95\% \text{ CL limits} \]

\[ \text{gluon-gluon fusion} \]

\[ \text{ATLAS} \]

\[ \text{Expected} \]

\[ \pm 1\sigma \]

\[ \pm 2\sigma \]

\[ \text{ATLAS 2015} \]

\[ \text{Observed} \]

\[ \text{Expected} \]

\[ \text{Observed} \]

\[ \pm 1\sigma \]

\[ \pm 2\sigma \]

\[ \text{Expected} \]

\[ \text{Expected} \]
systematic uncertainties

**ATLAS**
\( \sqrt{s} = 13 \text{ TeV}, 36.1 \text{ fb}^{-1} \)

- **Gluon-gluon fusion**
- **B-associated production**

![Gluon-gluon fusion](image1)

![B-associated production](image2)
HL-LHC projection

**ATLAS Preliminary**

- **Baseline**
- **5σ sensitivity**

**Projection from Run-2 data**

- $\sqrt{s} = 14$ TeV, 3000 fb$^{-1}$

**gluon-gluon fusion**

$$\sigma \times \text{BR}(\phi \to \tau\tau) \text{[pb]}$$

- $m_\phi$ [GeV]

**b-associated production**

$$\sigma \times \text{BR}(\phi \to \tau\tau) \text{[pb]}$$

- $m_\phi$ [GeV]
HL-LHC projection

**MSSM** $m_{\tilde{t}}$ mod+ scenario

**hMSSM** scenario