Searches for BSM Higgs bosons @ ATLAS

Doubly charged Higgs candidate

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Introduction

- Higgs boson 2012-discovery completed the SM
  - $h(125)$ looks very SM-like so far

- Still important phenomena are not included

- Several models beyond the SM (BSM) proposed as solutions to these issues which imply additional Higgs bosons
  - Neutral (CP-even $H$, CP-odd $A$)
  - Charged (singly $H^\pm$, doubly $H^{\pm\pm}$)

- Searches for BSM Higgs bosons performed by looking at:
  - Fermionic, bosonic, di-higgs decays
  - Deviations from SM in rare and invisible decays

**BR to BSM decays < 34% @ 95%CL**

arXiv:1606.02266
BSM Higgs

- **Electroweak Singlet**
  - Addition of real scalar singlet results in two bosons: $h$ and $H$

- **Two Higgs Doublet Model (2HDM)**
  - 2 Higgs doublets $\phi_1$ and $\phi_2$
  - 5 Higgs bosons: $h$, $H$, $A$, $H^\pm$
  - Several types depending on the couplings
  - Many parameters: $\tan \beta = v_1/v_2$, mixing angle $\alpha$, masses

- **Minimal Supersymmetric SM (MSSM)**
  - SUSY in its minimal form
  - Type-II 2HDM with 5 Higgses $h$, $H$, $A$, $H^\pm$
  - 2 parameters at LO: $\tan \beta$ and $m_A$
  - Phenomenological scenarios ($hMSSM$, $m_h^{max}$, $m_h^{mod\pm}$)

- **Higgs Triplet Model (HTM)**
  - $\phi^{++}$, $\phi^+$, $\phi^0$
  - Includes $H^{\pm\pm}$

*Run-1 exclusion limits for hMSSM*
Summary of results

- Searches performed with the ATLAS detector
  - Run-2 data at $\sqrt{s} = 13$ TeV: partial 2016 + full 2015 (~15fb$^{-1}$), full 2015 + 2016 (~36fb$^{-1}$)
  - Results presented as:
    - Discovery!
    - Limits on production cross section of new Higgs bosons
    - Constraints on BSM physics benchmark scenarios

- Neutral $H$ to bosons
  \[ H \rightarrow \gamma\gamma \]
  \[ H \rightarrow WW \rightarrow l\nu qq' \]
  \[ H \rightarrow ZZ \rightarrow 4l/2l2\nu \]

- Neutral $H$ to fermions
  \[ A/H \rightarrow \tau\tau \]

- Neutral $H$ to SM di-higgs
  \[ H \rightarrow hh \rightarrow WW\gamma\gamma \]

- Charged Higgs
  \[ H^\pm \rightarrow \tau^\pm\nu \]
  \[ H^\pm \rightarrow tb \]
  \[ H^{\pm\pm} \rightarrow 4l \]

- Invisible and rare decays
  \[ H \rightarrow inv \ (ZH \rightarrow ll + E_T^{miss}) \]
  \[ H \rightarrow Z\gamma \]
  \[ H \rightarrow \phi\gamma/H \rightarrow \rho\gamma \]
Neutral Higgs Boson to Bosonic final states
Two high-$p_T$ photon final state

In 2015 ATLAS and CMS reported $\sim 3\sigma$ excess around 750 GeV with 3.2 fb$^{-1}$

Latest result with 11 times that data shows no excess within $1\sigma$

Spin-0 and spin-2 (RS-model and KK-graviton) resonances search

@750GeV: $3.0\sigma_{\text{local}}, 0.8\sigma_{\text{global}}$
**H → WW/WZ → lνqq’**

- WW/WZ resonance search in the NWA (4 GeV)
- One W decays leptonically and the other boson to hadrons
  - Boosted boson tagging
- 2 production modes considered: VBF and ggF
- Three signal hypothesis considered:
  - HVT, RS graviton, NW heavy scalar

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**ATLAS Preliminary**

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

**DY Category**

- Data
- W+jets
- tt
- Single t
- Dibosons
- Z+jets
- Post-fit uncertainty
- HVT Model A Z’
- 2000 GeV (+5)

**Observed 95% CL upper limit**

**Expected 95% CL upper limit (± 1σ)**

**Expected limit (± 2σ)**

**m(Scalar) [TeV]**

0.5  1  1.5  2  2.5  3  3.5  4

10^{-3}  10^{-2}  10^{-1}  1  10  100  10^{3}
**H → ZZ → 4 leptons**

- Resonance search in the 4l and 2l2ν final states using m_{4l} and m_{T}, respectively
  - Fully reconstructed pair of Zs decaying to 4 leptons
- Heavy higgs (H) in ggF and VBF modes decaying to ZZ in a NWA
  - Events with 2 separated jets with high dijet mass: VBF, ggF otherwise
- Also LWA considered
- Interpretation for bulk Randall-Sundrum Graviton Model and Heavy Scalar

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**ATLAS Preliminary**

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

\[ H \rightarrow ZZ \rightarrow l^+l^-l'^{+}l'^{-} \]

\( ggF \)-enriched

\[ m_{4l} \text{ [GeV]} \]

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

**4l – ggF-enriched**

**2l2ν – VBF-enriched**
Data excess in NWA at 240 and 700 GeV predominantly in $ggF$ 4$\ell$ categories
- $3.6\sigma$ (local), $2.2\sigma$ (global)

Also exclusion limits in 2HDM, RS graviton and LWA
Neutral Higgs Boson to Fermionic final states
Heavy resonance search in di-tau events
- Two final states: semileptonic tau decays and fully hadronic

Promising search for high $\tan\beta$

Two main categories: b-tagged ($bbH$) and b-veto ($ggF$)

Results interpreted in many MSSM scenarios
- Large $\tan(\beta)$ enhances H coupling to down fermions (tau, b)
Excursion limits on $\sigma \times BR$ for model independent (ggF, bbH) and model dependent ($m_h^{\text{mod+}}$, hMSSM)
Charged Higgs Boson
- **Final state:** $\tau$, $E_T^{\text{miss}}$ and a top quark
  - Fully hadronic $\tau$ decays

- Limits on production cross section and parameter values

- Results interpreted in various scenarios
  - MSSM shown

- No significant excess
- Same production mode as in previous result
- Final state: 1 lepton, $E_T^{\text{miss}} + \text{jets (some b-jets)}$
- Events categorized in different signal/control regions
  - Use MVA technique for final discriminant
  - Simultaneous fit in all regions
- Result interpreted in $m_h^{\text{mod-}}$ scenario of MSSM
Doubly charged Higgs bosons from many BSM scenarios
- Pairs of high-$p_T$ isolated SS leptons ($e, \mu$)
  - Prompt leptons, fake leptons and charge-flip backgrounds
- Fit several control and signal regions
- Limits assuming different BRs
Di-Higgs production
Large BR of WW and clean signature of two photons and 1 lepton
- Low BR of $\gamma\gamma$ limits sensitivity at high mass
Higgs boson rare or invisible decays
Clear signature for $ZH \rightarrow ll + E_T^{\text{miss}}$
  - The SM invisible decay ($H \rightarrow ZZ \rightarrow 4\text{neutrinos}$) has $BR \sim 10^{-3}$

Assume SM ZH production to place upper limit on $B(H \rightarrow \text{inv})$

Interpret result in DM models with BSM vector mediator

Small excess in $\mu\mu$ channel (2.2$\sigma$)
- Exclusion limit on $B(H \rightarrow \text{inv})$ assuming SM ZH cross section: 67% (observed)

- 95% exclusion limit in 2D $m_\chi$ and $m_{\text{med}}$
  - Mediator mass excluded up to 560 GeV
  - WIMP mass ($m_\chi$) excluded up to 130 GeV
Final state coming from loop diagrams

Possible differences from SM prediction
  - H is a different neutral scalar
  - H is composite
  - Additional particles in the loops

Signal extracted from S+B fit to m(Zγ)
  - 6 categories and BDT discriminant

No significant excess observed w.r.t SM
  - \(2.7\) \(\sigma^{\text{local}}\), \(0.8\) \(\sigma^{\text{global}}\) @ 960 GeV

\[\text{arXiv:1708.00212}\]
Conclusions

- Very active ATLAS’ search for BSM phenomena in the Higgs sector
  - Results with partial / full 2016 data presented

- Only a small fraction of results shown here
  - Checkout ATLAS public results at
    [https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults](https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults)

- No significant excesses over SM have been found so far
  - 10 fb⁻¹ of 2017 data being analyzed and x10 full 2016 statistics for full Run-2!
Back Up
- Processes sensitive to light quarks couplings to the Higgs
- SM expectation: $B(\text{H} \rightarrow \phi \gamma) \sim 10^{-6}$ and $B(\text{H} \rightarrow \rho \gamma) \sim 10^{-5}$
- Final state reconstructed from two high-pT isolated tracks consistent with $\phi$ or $\rho$ with a recoiling photon

- Observed 95% CL upper limits on branching fractions for $\text{H} \rightarrow \phi \gamma$ ($\text{H} \rightarrow \rho \gamma$) decays are around $208$ ($52$) the expected SM