Beyond-the-Standard Model Higgs Physics using the ATLAS Experiment

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Introduction

• We observed a Standard Model-like Higgs boson at $m_H=125$ GeV
  – is it a Standard Model Higgs boson indeed?
• There is a lot of room for non-SM interpretation!
  – Higgs with non-SM couplings (e.g. fermiophobic)
  – Part of a bigger family (MSSM, 2HDM, triplets)
  – NMSSM
MSSM Higgs $\phi \rightarrow \mu \mu / \tau \tau$

- Production: gluon fusion, $b$-associated production
  - separated into $b$-tagged and $b$-vetoed
- $\tau \tau$ channel: three groups ($e\mu$, $l+\text{had}$, $\text{had}+\text{had}$)

<table>
<thead>
<tr>
<th>$e\mu$</th>
<th>$l+\text{had}$</th>
<th>$\text{had}+\text{had}$</th>
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</thead>
<tbody>
<tr>
<td>$p_{T_e}&gt;25$ GeV, $p_{T}\mu&gt;20$ GeV, $p_{Tl}+\text{MET}&lt;120$ GeV, $\Delta \varphi(e\mu)&lt;2$</td>
<td>$p_{T}/\mu&gt;25/20$ GeV, $p_{T}\tau&gt;20$ GeV, $\text{MET}&gt;20$ GeV, $M_{T}&lt;30$ GeV</td>
<td>$p_{T}\tau&gt;30/45$ GeV, $\text{MET}&gt;25$ GeV</td>
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- $\mu \mu$ channel:
  - $p_{T}>20$ GeV,
  - $|\eta|<2.5$,
  - $\text{MET}<40$ GeV

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MSSM Higgs $\phi \rightarrow \mu\mu/\tau\tau$: results

- Obtain combined limits for both channels
  - $\tan\beta$ vs $m_A$ in $m_h^{\text{max}}$, $\mu>0$ MSSM scenario
  - Limit on production for a generic single scalar boson decaying into $\mu\mu/\tau\tau$
2HDM generic Higgs

- Search for heavier neutral CP even partner of 125 GeV Higgs
- Production: gluon fusion, VBF    Decay: $H \rightarrow WW^* \rightarrow e\nu \mu\nu$
- Selection: $p_T > 25/15$ GeV, MET > 25 GeV, 0 or 2 jets
- Use neural network to separate signal from background
  - 0 jets has better S/B but worse NN separation

![Graphs showing event fraction and NN output distributions for different scenarios.](image-url)
2HDM generic Higgs: results

- No evidence found in the 135—300 GeV mass region
- Limits set for two models in terms of $\alpha$, $\beta$, $m_H$
  - Type-I: all quarks couple to only one Higgs doublet
  - Type-II: $+2/3$ RH quarks couple to one HD, $1/3$ RH quarks couple to the other HD

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Invisible Higgs

- Production: associated ZH, $Z \rightarrow ll$ ($l=e,\mu$)
- H decay: stable/long lived weakly interacting particles
- Selection: $pT_l > 15$ GeV, $|m_{ll} - m_Z| < 15$ GeV, MET $> 90$ GeV, topo
- Limits are set in two scenarios:
  - on invisible BR of a SM Higgs at $m_H = 125$ GeV: at 95% C.L. observed/expected limits are 65%/84%
  - on production×BR of a Higgs-like particle vs $m_H$

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Assume that diphotons from a decays are highly collimated and result in a single EM cluster.

Selection: similar to $h \rightarrow \gamma \gamma$ but dedicated EM cluster reconstruction to detect photons from Higgs decays.

Limits on prod×BR for $m_a=100, 200, 400$ MeV.
Charged Higgs

- Charged Higgs appears in many BSM scenarios (e.g. 2HDM)
- SM doesn’t have H+, so its observation would indicate BSM
- H+ production and decay depends on mH+ compared to mt

<table>
<thead>
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<th>Light H+</th>
<th>Heavy H+</th>
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</thead>
<tbody>
<tr>
<td>production</td>
<td>tt→bW bH+</td>
<td>gb→tH+, gg→tbH+</td>
</tr>
<tr>
<td>dominant decay modes</td>
<td>H+→τν (low tanβ), H+→cs (high tanβ)</td>
<td>H+→tb, τν, χ+χ0</td>
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</tbody>
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- Presenting results for both light and heavy charged Higgs

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Light charged Higgs $H^+ \rightarrow \tau \nu$

- $tt \rightarrow bbWH^+$, $W \rightarrow qq$, $H^+ \rightarrow \tau$(had)$\nu$
- Selection: $\geq 4$ jets, $\geq 1$ b-jet, $\tau$(had vis) pT$>40$ GeV, second e/µ/τ veto, MET$>65$ GeV, cut on MET/$\sqrt{\sum p_T}$(vtx trk)
- Discriminating variable: $\tau$(had vis) + MET transverse mass
- Limits are set on $Br(t \rightarrow H+b)$ and (for MSSM $m_{h_{max}}$) on tan $\beta$
Heavy charged Higgs $H^+ \rightarrow \tau \nu$

- $t(b)H^+ \rightarrow b(b)WH^+, W \rightarrow qq, H^+ \rightarrow \tau(\text{had})\nu$
- Selection: $\geq 3$ jets, $\geq 1$ b-jet, $\tau(\text{had vis})$ $p_T > 40$ GeV, second e/\(\mu/\tau\) veto, MET $> 80$ GeV, cut on MET/$\sqrt{\Sigma p_T(\text{vtx trk})}$
- Discriminating variable: $\tau(\text{had vis}) + \text{MET transverse mass}$
- Limits are set on $\text{Br}(t \rightarrow H^+ b)$ and (for MSSM $m_h^{\text{max}}$) on $\tan \beta$

**ATLAS-CONF-2013-090**

**new!**

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Light charged Higgs $H^+ \rightarrow cs$

- $tt \rightarrow bbWH^+, \ W \rightarrow l\nu$
- Selection: $e/\mu \ p_T > 20 \ GeV, \geq 4 \ jets \ (p_T > 20 \ GeV), \geq 1 \ b$-jets, $MT > 25 \ GeV, \ MT + MET > 60 \ GeV$
- Look for a second peak in dijet mass, set limits on $Br(t \rightarrow bH^+)$

Doubly charged Higgs

- Appears in LR symmetric models, Seesaw Type II, Little Higgs
- Possible way to probe origin of neutrino masses at the LHC!
- Production: mostly pairs (DY-like) $H^{++} H^{--}$
- Method: generic same-sign dilepton spectrum search
  - $p_{T\text{e}}>25$ GeV, $p_{T\mu}>20$ GeV, $Z$-window

Search for FCNC in $t \rightarrow cH$, $H \rightarrow \gamma \gamma$

- In SM, FCNC are forbidden at tree level, suppressed by GIM mechanism at higher orders
  - observation $\rightarrow$ direct indication of new physics
- Selection: two photons ($p_T > 40/30$ GeV)
  - $t\bar{t} \rightarrow bW cH \rightarrow bjj \gamma \gamma$: $\geq 4$ jets, $\geq 1$ b-jet, top mass cuts
  - $t\bar{t} \rightarrow bW cH \rightarrow bl\nu \gamma \gamma$: $1$ e/\mu, $m_T > 30$ GeV, $\geq 2$ jets, $\geq 1$ b-jet, top mass cuts
- Observed/expected limits at 95% CL:
  - $\text{Br}(t \rightarrow cH)$: $0.83/0.53\%$, $tcH$ coupling $0.17/0.14$

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Conclusions

• ATLAS has a wide physics program on BSM Higgs
  – many analyses on full Run I data set are still to be completed
• In spite of SM-like Higgs observed, many BSM channels remain relevant
  – some models get restricted which improves their prediction power
• Looking forward to new exciting discoveries!
Backup
ATLAS: A Toroidal LHC ApparatuS

- muon detectors
- tile calorimeter
- liquid argon calorimeter
- toroid magnets
- solenoid magnet
- tracker (SCT, pixel, TRT)

Diameter: 25 m
Length: 46 m
Weight: 7000 tons
Total cable length: 3000 km