Searches for rare and BSM decays at ATLAS and CMS

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on behalf of the ATLAS and CMS Collaborations
Outline

Introduction

**Rare and BSM decays at ATLAS**

- $h \rightarrow \mu\mu$
- $h \rightarrow$ invisible ($+ Z \rightarrow ll$)
- $h \rightarrow Z\gamma$
- $h \rightarrow \phi\gamma, \rho\gamma$
- $t\bar{t} \rightarrow Wb + q(H \rightarrow \gamma\gamma)$
- $h \rightarrow ZZ_d, Z_dZ_d, aa \rightarrow 4l$

**Rare and BSM decays at CMS**

- $h \rightarrow$ invisible (VBF)
- $h \rightarrow$ invisible ($+ Z \rightarrow ll$)
- $h \rightarrow$ invisible ($+ V(jj)$, monojet)
- LFV Higgs decays
- $h \rightarrow aa \rightarrow 4\tau, 2\mu2\tau, 2\mu2b$

Summary
Introduction

- BSM decays of SM particles an integral part of the search for new phenomena at the LHC

- Deviations from SM prediction in rare decays would be a very strong indication for underlying non-SM physics

- Many different models predict rare/BSM decays of SM particles, such as Higgs portal to DM, 2HDM(+S), extra dimensions, composite Higgs

- Large number of searches, I will focus on the results from ~ the past year from each experiment
$h \rightarrow \mu\mu$ (1/2)

Selection overview

- Single muon triggers (26 GeV isolated or 50 GeV muon)
- Two OS muons, $E_T^{\text{miss}} < 80$ GeV, $110 < m_{\mu\mu} < 160$ GeV, no b-tagged jets
- Events with $N_{\text{jet}} \geq 2$ are passed through a multivariate discriminant. Two VBF categories ($0.7 < \text{BDTscore} < 0.9$ and $\text{BDTscore} > 0.9$) are defined.
- Events with fewer jets or lower score are sorted into 6 ggF categories:
  - $3 p_T^{\mu\mu}$ ranges $\times$ 2 pseudo-rapidity regions (central and forward)

$L = 36.1 \text{ fb}^{-1}$
• Observed (expected) 95% CL upper limit on signal strength set at 3.0 (3.1) times SM

• Limit driven by statistical uncertainty (systematic uncertainty has ~2.2% impact on limit)

• Result combined with Run-1 ATLAS data, signal strength upper limit set at 2.8 (2.9) times SM

• Improves on earlier CMS Run-1 result that set limit at 7.4 times SM

• CMS and ATLAS performed a combination in this channel, giving a best-fit value of the signal strength of 0.1 times SM
\[ h \rightarrow Z(\rightarrow ll)\gamma \] (1/2)

Selection overview

- Single lepton and dilepton triggers. Require 2 same-flavor OS isolated leptons (e or \(\mu\)) and at least one photon
- A constrained kinematic fit is applied to re-compute the momenta of the lepton pairs using the expected Z boson lineshape. An FSR correction also applied to lower \(m_Z\) \(\mu\mu\) events
- Search is split into a low mass category for Higgs decays (115 < \(m_{Z\gamma}\) < 170 GeV) and a high-mass resonance search (200 < \(m_{Z\gamma}\) < 2500 GeV)
- The \(h \rightarrow Z\gamma\) search is sub-divided into 6 categories:
  1. VBF-enriched: events with at least 2 jets that score highly with a dedicated VBF BDT
  2. High relative \(p_T\): events with a high \(p_T\) photon \(\left(\frac{p_T^\gamma}{m_{Z\gamma}} > 0.4\right)\).
  3. High \(ee\) \(p_{T_{TL}}\): \(p_{T_{TL}} > 40\) GeV
  4. Low \(ee\) \(p_{T_{TL}}\): \(p_{T_{TL}} < 40\) GeV
  5. High \(\mu\mu\) \(p_{T_{TL}}\): \(p_{T_{TL}} > 40\) GeV
  6. Low \(\mu\mu\) \(p_{T_{TL}}\): \(p_{T_{TL}} < 40\) GeV

, where \(p_{T_{TL}}\) is the component of \(p_{T}^Z\) perpendicular to \(\hat{p}_Z - \hat{p}_\gamma\) and highly correlated to \(p_{T}^Z\) but with better experimental resolution.
- The high-mass search divided into \(ee\) and \(\mu\mu\) categories
Improves upon earlier CMS Run-1 result with observed limit of 9.5 times SM prediction
Probes Higgs coupling to light quarks

The $\rho \to \pi^+\pi^- (\phi \to K^+K^-)$ decay is used to reconstruct the $\rho$ ($\phi$)

Selection overview

- Dedicated triggers that require a photon with $p_T > 35$ GeV and a pair of isolated ID tracks with $p_T > 15$ GeV and invariant mass consistent with the $\rho$ or $\phi$ hypotheses
- Mass windows of $635 < m_{\pi^+\pi^-} < 915$ MeV and $1012 < m_{K^+K^-} < 1028$ MeV
- Meson $(M)$ $p_T > 40 - 47$ GeV, highest $p_T$ photon used, $\Delta\phi(M, \gamma) > \frac{\pi}{2}$.
- Background dominated by multijet and photon + jet
- Background templates extracted from CR with looser isolation, lower $p_T$ cuts
- Background normalized in $m_{K^-K^+}$, $m_{\pi^-\pi^+}$ sidebands

\[ \mathcal{L} = 35.6 \text{ fb}^{-1} \]
\[ h \rightarrow \phi \gamma, \rho \gamma \ (2/2) \]

- Observed yields consistent with SM prediction
- 95\% CL upper limits on the \( B(h \rightarrow \phi \gamma) \) and \( B(Z \rightarrow \phi \gamma) \) are 208 and 87 times SM, respectively
- 95\% CL upper limits on \( B(h \rightarrow \rho \gamma) \) and \( B(Z \rightarrow \rho \gamma) \) are 52 and 597 times SM, respectively
$t\bar{t} \rightarrow Wb + q (H \rightarrow \gamma\gamma)$

- The decay of $t \rightarrow qH$ where $q = c, u$ proceeds via a FCNC and is negligible in the SM
- BSM models such as 2HDM, RPV SUSY and composite Higgs allow for BRs orders of magnitude beyond the SM BR
- The search is done in the clean $H \rightarrow \gamma\gamma$ decay mode, using 36.1 fb$^{-1}$ Run-2 data and a diphoton trigger
- Both hadronic and leptonic $W$ decays are considered
- Simulated $\gamma\gamma j$ normalised to data in $m_{\gamma\gamma}$ sideband

**Hadronic selection**
- At least 4 jets, one must be $b$-tagged
- Two 3-body objects with masses $(M_1, M_2)$ compatible with top masses
  - $M_1 \in [152,190]$ GeV, $M_2 \in [120,220]$ GeV.
- Events that fail $M_2$ mass window still used in final analysis (“category 2”)
  - $m_{\gamma\gamma} \in [122,129]$ GeV

$L = 36.1$ fb$^{-1}$

*briefly mentioned in H. Yang’s gammagamma talk*
\[ t\bar{t} \rightarrow Wb + q(H \rightarrow \gamma\gamma) \]

- Main background is \( \gamma\gamma j, V\gamma\gamma \) and \( t\bar{t}\gamma \)
- After selection, categories 1 and 2 have only 3 events each
- Simulated \( \gamma\gamma j \) normalised to data in \( m_{\gamma\gamma} \) sideband

**Leptonic selection**

- 2 photons, at least 2 jets and one e or \( \mu \). One of the jets must be \( b \)-tagged
- \( m_T(l, p_T^{miss}) > 30 \) GeV
- Two 3-body objects compatible with \( t\bar{t} \) masses
- \( M_{\gamma\gamma j} \in [152,190] \) GeV, \( M_{jlv} \in [130,210] \) GeV.
- Events failing the \( M_{jlv} \) window cut fall in category 2
\[ t\bar{t} \rightarrow Wb + q(H \rightarrow \gamma\gamma) \]

- The observed (expected) 95% CL upper limit on \( B(t \rightarrow cH) \) is \( 2.2 \times 10^{-3} \) (1.6 \( \times 10^{-3} \))
- Analysis is almost equally sensitive to \( t \rightarrow uH \), with observed (expected) upper limits of \( 2.4 \times 10^{-3} \) (1.7 \( \times 10^{-3} \))
- Branching ratio limits translated to limits on off-diagonal Yukawa couplings: \( \lambda_{tch} < 0.090 \) (0.077) and \( \lambda_{tch} < 0.094 \) (0.079)
- Improves upon Run-1 CMS result
$Z (\rightarrow ll) + h \rightarrow \text{inv (1/2)}$

- Search for invisibly decaying Higgs or BSM-mediated WIMP pair production, produced alongside $Z \rightarrow ll$ using 36.1 fb$^{-1}$ 13 TeV data
- Main backgrounds are $ZZ$ and $WZ$
- $ZZ$ is taken from simulation, $WZ$ as well but scaled with data-driven scale factor obtained in a high $m_T^W$, $N_l > 2$ CR
- $Z$+jets is $\sim 8\%$ of total background, estimated with a data-driven ABCD method

Selection overview
- Single lepton triggers
- Require a boosted $Z$ recoiling off $p_T^{\text{miss}}$. Veto events with $b$-jets and $N_l > 2$
- $E_T^{\text{miss}} > 90$ GeV, $E_T^{\text{miss}} / H_T > 0.6$
- $\Delta \phi (p_T^{ll}, p_T^{\text{miss}}) > 2.7$, $\Delta R_{ll} < 1.8$
- $|p_T^{ll} - p_T^{\text{miss}}| / p_T^{ll} < 0.2$

$\mathcal{L} = 36.1$ fb$^{-1}$
$Z(\rightarrow ll) + h \rightarrow \text{inv} \ (2/2)$

- The $E_T^{\text{miss}}$ distribution is used as a discriminant.
- No significant excess over SM background expectation is observed.
- The observed (expected) 95% CL upper limit on $B(h \rightarrow \text{inv})$ for the combined $ee + \mu\mu$ search is 67% (39%).
- Observed limit is worse due to a 2.2σ data excess in the $\mu\mu$ channel.
- Limits are also placed on the $m_\chi, m_{\text{med}}$ masses, excluding $m_\chi$ up to 130 GeV for $m_{\text{med}} = 400$ GeV, and $m_{\text{med}}$ up to 560 GeV for light $m_\chi$. 

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08/26/17

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CMS-HIG-16-016

CMS has done a combination of several searches for invisible decays targeting qqH, VH and gluon+H production using both Run-1 and Run-2 data

<table>
<thead>
<tr>
<th>Production</th>
<th>Final state</th>
<th>Run-1 (fb⁻¹)</th>
<th>Run-2 (fb⁻¹)</th>
</tr>
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<tr>
<td>qqH</td>
<td>VBF jets</td>
<td>19.2</td>
<td>2.3</td>
</tr>
<tr>
<td>VH</td>
<td>Z → ll</td>
<td>24.6</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>Z → b̅b</td>
<td>18.9</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>V → jj</td>
<td>19.7</td>
<td>2.3</td>
</tr>
<tr>
<td>ggH</td>
<td>monojet</td>
<td>19.7</td>
<td>2.3</td>
</tr>
</tbody>
</table>
$h \rightarrow$ invisible (VBF)

Selection overview

- Uses dedicated VBF trigger, requires presence of a forward-backward jet pair with $p_T^{j_1} > 50$ (80), $p_T^{j_2} > 45$ (70) GeV, $|\eta^j| < 4.7$ and $|\Delta\eta^{jj}| > 3.6$
- Also requires $m_{jj} \gtrsim 1200$ (1100) GeV and $E_T^{\text{miss}} > 90$ (200) GeV at 8 (13) TeV. A $S(E_T^{\text{miss}}) = \sqrt{E_T^{\text{miss}}} > 4 \sqrt{\text{GeV}}$ is applied to 8 TeV data
- Can reduce QCD background by requiring $\min \Delta\phi(p_T^{\text{miss}}, j) > 2.3$
- Veto events with an $e$ or $\mu$

- Main backgrounds are $Z(\rightarrow \nu\nu) + \text{jets}$ and $W(\rightarrow l\nu) + \text{jets}$, with a common scale factor obtained in a simultaneous fit in dimuon and single lepton CRs
- Multijet is extrapolated from CRs defined by inverting or loosening $\Delta\phi(E_T^{\text{miss}}, j)$ and $S(E_T^{\text{miss}})$ cuts. All CRs are simultaneously fit with a floating multijet SF
\[ h \rightarrow \text{invisible (Z} \rightarrow ll) \]

- Lower cross-section than qqH but cleaner final state
- Background dominated by diboson events, estimated via simulation
- Events with \( N_l > 2, N_{jet} > 1 \) or \( \mu + b\)-jet are vetoed to suppress diboson and \( t\bar{t} \)

## Selection overview

### Double (and single) lepton triggers

<table>
<thead>
<tr>
<th>Condition</th>
<th>7 and 8 TeV</th>
<th>13 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p_T^{e,\mu} )</td>
<td>&gt; 20 GeV</td>
<td></td>
</tr>
<tr>
<td>( m_{ll} )</td>
<td>76 – 106 GeV</td>
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<tr>
<td>( \Delta \phi(l, l) )</td>
<td>-</td>
<td>&lt; ( \pi/2 )</td>
</tr>
<tr>
<td>( E_T^{miss} )</td>
<td>&gt; 120 GeV</td>
<td>&gt; 100 GeV</td>
</tr>
<tr>
<td>( \Delta \phi(ll, p_T^{miss}) )</td>
<td>&gt; 2.7</td>
<td>&gt; 2.8</td>
</tr>
<tr>
<td>( \Delta \phi(i, p_T^{miss}) )</td>
<td>-</td>
<td>&gt; 0.5</td>
</tr>
<tr>
<td>(</td>
<td>E_T^{miss} - p_T^{ll}</td>
<td>/p_T^{ll} )</td>
</tr>
<tr>
<td>( m_T )</td>
<td>&gt; 200 GeV</td>
<td></td>
</tr>
</tbody>
</table>

[Diagram showing CMS data for Z(\ell\ell) (0-jet) and Z(\ell\ell) (1-jet)]
$h \rightarrow \text{invisible } (V \rightarrow jj, \text{ monojet})$

- Main backgrounds are $Z(\rightarrow \nu\nu) + \text{jets}$ and $W(\rightarrow l\nu) + \text{jets}$. Multijet background is reduced by requiring the jets to be recoiling from $p_T^{\text{miss}}$
- $V(jj)$ events are identified by requiring a large $R=0.8$ jet, and exploiting 2 sub-jet topology variables such as the “subjettiness” $\tau_2/\tau_1$, pruned jet mass $m_{\text{prune}}$
- Events that fail the $V(jj)$ and with a $R=0.4$ jet are considered in the monojet search
- The $E_T^{\text{miss}}$ distribution is fitted in the SR and single or dilepton CRs. $\gamma + \text{jets}$ events are used to reduce stat uncertainties. Leptons and photons are removed from the $E_T^{\text{miss}}$ computation in the CRs

**Selection overview**

Triggers on events with high $E_T^{\text{miss}}$ and $p_T^j$ or $H_T^j = \Sigma p_T^j$

Veto events with leptons or $b$-jets

<table>
<thead>
<tr>
<th>8 TeV</th>
<th>13 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>V(jj)</td>
<td>Monojet</td>
</tr>
<tr>
<td>$p_T^j$</td>
<td>&gt; 200 GeV</td>
</tr>
<tr>
<td>$</td>
<td>\eta^j</td>
</tr>
<tr>
<td>$E_T^{\text{miss}}$</td>
<td>&gt; 250 GeV</td>
</tr>
<tr>
<td>$\tau_2/\tau_1$</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>$m_{\text{prune}}$</td>
<td>60 – 110 GeV</td>
</tr>
</tbody>
</table>

$\min \Delta \phi (j, p_T^{\text{miss}})$

<table>
<thead>
<tr>
<th>$N_j$</th>
</tr>
</thead>
<tbody>
<tr>
<td>= 1 (or 2 if $\Delta \phi_{jj} &lt; 0.2$)</td>
</tr>
</tbody>
</table>

$08/26/17$

P. de Bruin
$h \to \text{invisible} – \text{results}$

- No significant deviations from SM are observed
- Assuming SM production of $ggH$, $qqH$ and $VH$, a 95% CL upper limit of $B(H \to \text{inv}) < 0.24$ is set
- Upper limits as a function of the fermion and vector boson couplings, $\kappa_f$ and $\kappa_V$ shown
- Results are interpreted in the context of Higgs-portal DM interactions
- Results improve upon LUX for DM mass below 20 (5) GeV assuming a fermion (scalar) DM particle
LFV Higgs decays (1/2)

- LFV Higgs couplings allow $\tau \to \mu, \tau \to e, \mu \to e$ via a virtual H. Relevant for SUSY, R-S, composite Higgs and others
- Strong constraints from $\mu \to e\gamma$ give $B(H \to e\mu) < O(10^{-8})$. Less stringent constraint for $B(H \to e\tau), B(H \to \mu\tau)$
- 4 decay channels considered: $H \to e\tau_\mu, e\tau_\tau, \mu\tau_\mu$ and $\mu\tau_\tau$. Similar signature to SM but light leptons contain higher momentum fraction since prompt decay (instead of $\tau_\tau$). Backgrounds are $Z +$ jets, $W +$ jets and multijet
- Multijet background estimated using SS prediction. Multijet CR from looser lepton isolation used to extract SFs
- Fully data-driven prediction using $p_T$-dependent misidentification rates for $j \to e, j \to \mu$ and $j \to \tau_\tau$ events
- Mis-ID rates obtained in control regions defined by inverting separately or simultaneously the relative lepton sign and isolation

Selection overview

- Single lepton triggers
- Opposite sign, different flavor isolated leptons or lepton + $\tau_\tau$
- Four additional sub-categories according to production mode: VBF, 0-jet, 1-jet and 2-jet

$\mathcal{L} = 35.9$ fb$^{-1}$
LFV Higgs decays (2/2)

- Loose selection and a BDT discriminant used, but cross-checked with result from tighter selection and $M_{col}$ fit. BDT-fit analysis has limits ~2 stronger
- BDT input variables vary for each channel, but typically include $p_T^{l,\tau}, E_T^{miss}, M_{col}, M_T^{l,\tau}$ and angular variables between $l, \tau_h$ and $p_T^{miss}$
- Results are compatible with background expectation. 95% CL upper limit on $B(H \to e\tau)$ and $B(H \to \mu\tau)$ set at 0.25% and 0.61%, respectively
- Limits on off-diagonal $e\tau, \mu\tau$ Yukawa couplings set
- Improves on Run-1 ATLAS and CMS results
$H \rightarrow ZZ_d, XX \rightarrow 4l$

- Search for $ZZ_d, Z_d Z_d$ or $aa$ in 4-lepton final states. Relevant for $U(1)_d$ or 2HDM+S extensions of the SM
- Dominant backgrounds are SM $H \rightarrow ZZ^* \rightarrow 4l$, followed by non-resonant $ZZ^* \rightarrow 4l$

- Selection summarized in table, mostly angular separation between leptons and mass window cuts around $m_h, m_Z$ and allowed range for $m_{Z_d}$ and $m_\alpha$.
- Low mass selection only considers $4\mu$ final state
- $J/\psi$ and $Y$ backgrounds removed via dedicated mass window cuts

$$L = 36.1 \text{ fb}^{-1}$$
$H \rightarrow ZZ_d, XX \rightarrow 4l$

- $ZZ_d$ search observes 102 events to $87 \pm 7$ predicted
- Low mass $XX$ search observes no events to a predicted $0.4 \pm 0.1$
- High mass $XX$ search observes 6 events, to a predicted $3.9 \pm 0.3$. There’s a $3.8\sigma$ local significance excess at 20 GeV, but due to only one event
- 95% CL upper limits on the Higgs branching ratio to $ZZ_d, Z_dZ_d$ and $aa$ are set as a function of the BSM boson mass
- Limits on model-independent fiducial cross-sections are also derived
Searches for $h \rightarrow aa$ decay in the 4$\tau$, 2$\mu$2$\tau$, 2$\mu$2$b$ using Run-1 data

Relevant for 2HDM+S models such as NMSSM. Considers final states from ggF, VBF and VH production

Overview of $h \rightarrow aa \rightarrow 4\tau$

- Single isolated muon trigger
- Only jets with a muon considered for tau pair reconstruction. First identify $\tau_\mu$ then reconstruct other tau ($\tau_X$) from jet while subtracting muon contribution. Doesn’t consider bottom quark seeded jets
- Main backgrounds are $Z/\gamma^* \rightarrow \mu\mu +$ jets, $W \rightarrow \mu\nu +$ jets, $t\bar{t}$ and multijet
- At least one OS $\tau_\mu \tau_X$ pair in event
- Reduce Drell-Yan by having trigger muon be SS as $\tau_X \cdot m_{\mu+X} \geq 4$ GeV gives 95% background rejection
- Analysis split into $m_T(\mu^{\text{trig}}, p_T^{\text{miss}})$ above or below 50 GeV
- Mis-ID background estimated as mean of independent predictions from 3 background-rich regions where the $\tau_X$ is not isolated, each normalized to data in $m_{\mu+X} < 2$ GeV region

$\mathcal{L} = 19.7 \text{ fb}^{-1}$
$h \rightarrow aa$

Overview of $h \rightarrow aa \rightarrow 2\mu 2b$

- Dimuon triggers
- $|m_{\mu\mu bb} - 125| < 25$ GeV,
- Main backgrounds from $Z/\gamma^* \rightarrow ll$ and fully leptonic $t\bar{t}$ decays
- Analytical functions are used for background and signal modelling and fit to $m_{\mu\mu} \in [25, 62.5]$ GeV in data

Overview of $h \rightarrow aa \rightarrow 2\mu 2\tau$

- 5 final states: $\mu^+\mu^-\tau^+\tau^-, \mu^+\mu^-\tau^\pm\tau^\mp, \mu^+\mu^-\tau_e\tau_\mu, \mu^+\mu^-\tau_\mu\tau_\tau, \mu^+\mu^-\tau_\tau\tau_\tau$ and $\mu^+\mu^-\tau_\tau\tau_\tau$
- Dimuon trigger. Pairs highest $p_T$ OS muons and taus, veto events with $b$-jets
- $|m_{\mu\mu\tau\tau} - 125| > 30$ GeV, $|m_{\mu\mu\tau\tau} - 125| < 25$ GeV, $|m_{\mu\mu} - m_{\tau\tau}| / m_{\mu\mu} < 0.8$
- Irreducible ZZ background taken from simulation. Reducible $Z+$ jets and $W+$ jets events estimated using $p_T$-dependent jet $\rightarrow e, \mu$ or $\tau$ mis-ID rates computed in looser isolation and SS control regions
- Analytical functions for signal and background are fitted to $m_{\mu\mu} \in [15, 62.5]$ GeV in data
\( h \rightarrow aa \) – limits

- 95\% CL upper limits on production times BR of each \( h \rightarrow aa \) decay mode are set as a function of the pseudoscalar mass

- 2 events in \( \mu^+\mu^-\tau_e^+\tau_e^- \) with \( m_{\mu\mu} \) equal to 18.4 and 20.7 GeV lead to a 3.5\( \sigma \) deviation. Expected background yield agrees with observed yield over full mass range
Above results combined with earlier $a a$ to $4\mu$ and $4\tau$ searches.

- No significant excess observed for any of the five analyses.
- Upper limits of 17%, 16% and 4% on $\frac{\sigma}{\sigma_{SM}} \times B(h \rightarrow aa)$ set from $4\tau$, $2\mu2b$ and $2\mu2\tau$ analyses, respectively.
- 95% CL upper limit also set separately for 2HDM+S of types 1, 2, 3 and 4.
## Previous results – ATLAS

<table>
<thead>
<tr>
<th>Search</th>
<th>$\sqrt{s}$</th>
<th>7 TeV (fb$^{-1}$)</th>
<th>8 TeV (fb$^{-1}$)</th>
<th>13 TeV (fb$^{-1}$)</th>
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<tr>
<td>$W^{+}(h \to aa \to 4b)$</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.2</td>
<td>Eur. Phys. J. C 76 (2016) 605</td>
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<tr>
<td>$t\bar{t} \to Wb+qH$</td>
<td>-</td>
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<td>VBF $h$ to invisible</td>
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## Previous results – CMS

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<td>19.7</td>
<td>-</td>
<td>CMS-HIG-14-040</td>
</tr>
<tr>
<td>ATLAS+CMS Higgs decays</td>
<td>√s</td>
<td>~5</td>
<td>~20</td>
<td>-</td>
<td>J. High Energy Phys. 08 (2016) 045</td>
</tr>
<tr>
<td>$h \rightarrow aa \rightarrow 4\tau$</td>
<td>√s</td>
<td>-</td>
<td>19.7</td>
<td>-</td>
<td>CMS-HIG-14-019</td>
</tr>
<tr>
<td>$h \rightarrow \gamma + inv$</td>
<td>√s</td>
<td>-</td>
<td>19.4</td>
<td>-</td>
<td>CMS-HIG-14-025</td>
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<tr>
<td>$h \rightarrow \mu\mu, ee$</td>
<td>√s</td>
<td>5.0</td>
<td>19.7</td>
<td>-</td>
<td>CMS-HIG-13-007</td>
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<tr>
<td>VBF + Zh, h to inv</td>
<td>√s</td>
<td>4.9</td>
<td>19.7</td>
<td>-</td>
<td>CMS-HIG-13-030</td>
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</tbody>
</table>
Summary

• Showed recent results of rare and BSM decay modes of SM particles investigated by ATLAS and CMS
• No significant deviations from the SM observed
• Improved constraints on BSM branching ratios and parameter space exclusion in a wide range of models
• Several searches statistically limited and will benefit from more data so stay tuned!

Thank you!
$h(\rightarrow \text{invisible}) + Z(\rightarrow b \bar{b})$

- 4 MET triggers used
- 3 MET categories defined: 100 – 130 (“low”), 130 – 170 (“intermediate”), >170 GeV (“high”)
- BDT score used as discriminant
- 95% CL upper limit on $\sigma_{B(h \rightarrow \text{inv})} / \sigma_{\text{SM}}$ set at 1.82 (1.99)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Low $E_T^{\text{miss}}$</th>
<th>Intermediate $E_T^{\text{miss}}$</th>
<th>High $E_T^{\text{miss}}$</th>
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</thead>
<tbody>
<tr>
<td>$E_T^{\text{miss}}$</td>
<td>100–130 GeV</td>
<td>130–170 GeV</td>
<td>&gt;170 GeV</td>
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<tr>
<td>$p_T^T$</td>
<td>&gt;60 GeV</td>
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<tr>
<td>$p_T^j$</td>
<td>&gt;30 GeV</td>
<td>&gt;30 GeV</td>
<td>&gt;30 GeV</td>
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<tr>
<td>$p_T^j$</td>
<td>&gt;100 GeV</td>
<td>&gt;130 GeV</td>
<td>&gt;130 GeV</td>
</tr>
<tr>
<td>$M_{jj}$</td>
<td>&lt;250 GeV</td>
<td>&lt;250 GeV</td>
<td>&lt;250 GeV</td>
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<tr>
<td>CSV(_{\text{max}})</td>
<td>&gt;0.679</td>
<td>&gt;0.679</td>
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<tr>
<td>CSV(_{\text{min}})</td>
<td>&gt;0.244</td>
<td>&gt;0.244</td>
<td>&gt;0.244</td>
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<tr>
<td>N additional jets</td>
<td>&lt;2</td>
<td>—</td>
<td>—</td>
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<tr>
<td>N leptons</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>$\Delta \phi(Z, H)$</td>
<td>&gt;2.0 radians</td>
<td>&gt;2.0 radians</td>
<td>&gt;2.0 radians</td>
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<tr>
<td>$\Delta \phi(E_T^{\text{miss}}, j)$</td>
<td>&gt;0.7 radians</td>
<td>&gt;0.7 radians</td>
<td>&gt;0.5 radians</td>
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<tr>
<td>$\Delta \phi(E_T^{\text{miss}}, E_T^{\text{miss _trk}})$</td>
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<td>&lt;0.5 radians</td>
<td>&lt;0.5 radians</td>
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<tr>
<td>$E_T^{\text{miss _significance}}$</td>
<td>&gt;3</td>
<td>not used</td>
<td>not used</td>
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</tbody>
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*CSV is the btagging algorithm