Search for Fermionic Higgs Boson Decays in $pp$ Collisions at ATLAS and CMS

Romain Madar on behalf of ATLAS and CMS collaboration

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The Higgs boson in a nutshell

**Fundamental interest:**
The Higgs boson is the **relic particle** of the Electroweak symmetry breaking:

\[ SU(2)_L \times U(1)_Y \rightarrow U(1)_{em} \]

(Lagrangian symmetry) \hspace{1cm} (Vacuum symmetry)
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**Status of couplings between the Higgs boson and other fields?**

- **Direct observation** of bosonic decays
- **Direct evidence** of fermionic decays
- **Indirect observation** of coupling to fermion (loop-induced production)
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Status of couplings between the Higgs boson and other fields?

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Key role of direct fermionic coupling:

- **Reduce** experimental uncertainties on coupling & branching ratios
- **Disantangle** potential new physics from SM coupling in loops
1. Production of $H(125)$

\[ \sigma_{\text{tot}}(H) = 22.1 \text{ pb} \quad \sigma_{\text{tot}}(Z) \sim 10^4 \text{ pb} \]

- **GGF (88%)**: High rate but loops, no specific topology
- **VBF (6.6%)**: Low rate but tree level, specific jet topology
- **VH (5%)**: Low rate but clean final state (leptons)
- **ttH (0.4%)**: Extremely low rate and busy final state

Decays of $H(125)$:
- **bb** decay: Largest BR, benefits from additional lepton to reduce $pp!b\bar{b}+X$.
- **tt** decay: Lower BR, cleaner signature
- **cc** decay: Impossible in hadron collider
- **mm** decay: Extremely low BR (0.02%), good mass resolution
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\[ \sigma_{\text{tot}}(H) = 22.1 \text{ pb} \quad \sigma_{\text{tot}}(Z) \sim 10^4 \text{ pb} \]

2. Decays of $H(125)$ (emphasis on fermionic decay)

- **$bb$ decay**: largest BR, benefits from additional lepton to reduce $pp \rightarrow b\bar{b} + X$.
- **$\tau\tau$ decay**: lower BR, cleaner signature
- **$cc$ decay**: impossible in hadron collider
- **$\mu\mu$ decay**: extremely low BR (0.02%), good mass resolution
Higgs boson searches in fermionic final state at LHC

Key particles identification (1/2)

$m_{\tau} = 1.78 \text{ GeV}$
$c\tau_{\text{life}} = 87 \mu\text{m}$

$\tau^-$

$W^-$

$\nu_\tau$

1. escaping $\nu$'s

$e^-, \mu^-, d$

$\bar{\nu}_e, \bar{\nu}_\mu, \bar{u}$

2. hadronic final

$BR_{\text{had}} \approx 65\%$

$\tau_{\text{had}} \approx$ narrower jet with lower track multiplicities
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\[ m_\tau = 1.78 \text{ GeV} \]
\[ c\tau_{\text{life}} = 87 \text{ \mu m} \]

1. escaping \( \nu \)'s

2. hadronic final

\[ \tau^- \]

\[ W^- \]

\[ e^-, \mu^-, d, \bar{u} \]

\[ \bar{\nu}_e, \bar{\nu}_\mu, \bar{\nu}_\tau \]

\[ B\mathcal{R}_{\text{had}} \approx 65\% \]

\[ \tau_{\text{had}} \approx \text{narrower jet with lower track multiplicities} \]

**ATLAS : \sim 7\ observables combined in a BDT**

**CMS : based on hadronic substructure**

**ATLAS & CMS**

\[ \varepsilon_\tau \sim 50\% \]

\[ \varepsilon_{\text{jets}} \sim 1\% \]
Key particles identification (2/2)

Based on $b$-hadron properties:
- $c\tau \sim$ few mm, higher mass
- Displaced vertex of high mass
- Semi-leptonic decay

Background: $c$-hadrons

Algorithm: multivariate techniques to exploit all these properties and their correlations ($\sim$ 5 input variables).
Key particles identification (2/2)

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Overview

1. Search for $H \rightarrow bb$ decay
2. Search for $H \rightarrow \tau\tau$ decay
3. Search for $H \rightarrow \mu\mu$ decay
4. Dedicated searches for $ttH$ production
### ATLAS and CMS analyses overview

Analyzed integrated luminosity ($\text{fb}^{-1}$) of 7 and 8 TeV collisions

#### $bb$ final state

<table>
<thead>
<tr>
<th></th>
<th>ATLAS</th>
<th>CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>GGF</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>VBF</td>
<td>-</td>
<td>19.0</td>
</tr>
<tr>
<td>VH</td>
<td>4.7+ 20.3</td>
<td>5.0 + 19.0</td>
</tr>
<tr>
<td>ttH</td>
<td>4.7</td>
<td>19.0</td>
</tr>
</tbody>
</table>

#### $\tau\tau$ final state

<table>
<thead>
<tr>
<th></th>
<th>ATLAS</th>
<th>CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>GGF</td>
<td>4.9 + 13.0</td>
<td>4.9 + 19.4</td>
</tr>
<tr>
<td>VBF</td>
<td>4.9 + 13.0</td>
<td>4.9 + 19.4</td>
</tr>
<tr>
<td>VH</td>
<td>-</td>
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</tr>
<tr>
<td>ttH</td>
<td>-</td>
<td>19.0</td>
</tr>
</tbody>
</table>

(bold: most sensitive process, gray: impossible to extract from background)

+ inclusive search in the **$\mu\mu$ final state** in ATLAS (20.7)

**Documentation:**
- ATLAS $H \rightarrow \tau\tau$: GGF+VBF
- ATLAS $H \rightarrow bb$: VH, ttH
- ATLAS $H \rightarrow \mu\mu$: inclusive
- CMS $H \rightarrow \tau\tau$: GGF+VBF, VH
- CMS $H \rightarrow bb$: VH, VBF
- CMS ttH: $\tau\tau$ and $bb$
Overview

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2. Search for $H \rightarrow \tau\tau$ decay

3. Search for $H \rightarrow \mu\mu$ decay

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Search for $H \rightarrow bb$

Which production mode for $bb$ final state?

All but gluon fusion

$\sigma_{\text{tot}}(b\bar{b}) \sim 10^7$ pb

- $qqbb$ final state: high bkg rate
- W/Z signature: most sensitive

Relevant observable: $m_{bb}$

Refined energy scale and resolution for $b$-jets, jet kinematics, soft lepton properties...

Improvement: $10\%$ - $15\%$

References:
- ATLAS-CONF-2013-079
- CMS PAS HIG-13-012
- CMS PAS HIG-13-011
Search for $H \rightarrow bb$

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All but gluon fusion

$\sigma_{\text{tot}}(b\bar{b}) \sim 10^7$ pb

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- jet kinematics
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- ...

Improvement: $\sim 10 - 15\%$

Higgs boson searches in fermionic final state at LHC
Search for $H \rightarrow bb$ decay

VH production

1. Analysis strategy: number of leptons $\equiv$ vector boson decay

$$b\bar{b} + \not{E}_T$$
$$b\bar{b} + \ell + \not{E}_T$$
$$b\bar{b} + \ell^+ \ell^-$$
VH production

1. **Analysis strategy**: number of leptons $\equiv$ vector boson decay

\[
\begin{align*}
    b\bar{b} + E_T & \quad b\bar{b} + \ell + E_T \\
    b\bar{b} + \ell^+\ell^- &
\end{align*}
\]

2. **Standard Model backgrounds**:
   - top quark production
   - $W/Z + bb$ production - same final state as signal
   - $W/Z + u/d/s/c$ (fake $b$-jet)
   - Multijets production (fake/non isolated lepton and $b$-jet)
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**VH production**

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![Diagram](image.png)

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3. **Main kinematic handles**:
   - $m_{bb}$ reconstruction (look for a bump in $m_{bb}$ distribution)
   - Transverse momentum of vector boson (higher $S/\sqrt{B}$ at high $p_T^V$)
Controlling the background

**General approach:** global fit of data over several categories of different background composition \((n_\ell, p_T^V, n_{b-jets})\)

- background normalization & shape
- account for signal contamination
- include systematics uncertainties (b-tagging, Jet Energy Scale, ...)

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### 0 lepton, low \(p_T[V]\)

![Graph 1](image1)

### 2 leptons, low \(p_T[V]\)

![Graph 2](image2)
Signal extraction

**Strategy**: exploit topology differences between signal and background

- Properties of \((b, \bar{b})\) system (mass, angle, color connection, ...)
- Direction of \(\mathbb{E}_T\) relative to \((b, \bar{b})\) system
- Consistency of \((\mathbb{E}_T, \ell)\) system as coming from \(W\) decay
- **ATLAS**: cut then look at \(m_{bb}\); **CMS**: **MVA** (+cut based as cross check)
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\[
\Delta \phi(\mathbb{E}_T, bb) \sim \pi
\]
Method validation

All these technics can be applied to extract $VZ(\to bb)$ production (very similar signature), as a validation of the experimental method.
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All these technics can be applied to extract $VZ(\rightarrow bb)$ production (very similar signature), as a validation of the experimental method.
Results of $VH(bb)$ search (1/3)

ATLAS Preliminary

$\sqrt{s} = 8$ TeV \int Ldt = 20.3 fb$^{-1}$

- Observed (CLs)
- Expected (CLs)

CMS Preliminary

$\sqrt{s} = 8$ TeV, $L = 19.0$ fb$^{-1}$

@125 GeV:
- exp: 0.94
- obs: 1.71

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PIC2013 - 04/09/13 - Beijing, China
Results of $VH(bb)$ search (2/3)
## Results of $VH(bb)$ search (3/3)

### ATLAS Prelim.

<table>
<thead>
<tr>
<th>$VH(bb)$, 7 TeV</th>
<th>Total uncertainty</th>
<th>$\sigma$(stat)</th>
<th>$\sigma$(sys)</th>
<th>$\sigma$(theo)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$VH$, 0 lepton</td>
<td>$\pm 1.1$</td>
<td>$\pm 0.9$</td>
<td>$\pm 0.2$</td>
<td>$\pm 0.1$</td>
</tr>
<tr>
<td>$VH$, 1 lepton</td>
<td>$\pm 1.8$</td>
<td>$\pm 1.6$</td>
<td>$\pm 0.8$</td>
<td>$\pm 0.6$</td>
</tr>
<tr>
<td>$VH$, 2 leptons</td>
<td>$\pm 3.1$</td>
<td>$\pm 1.6$</td>
<td>$\pm 1.2$</td>
<td>$\pm 1.1$</td>
</tr>
</tbody>
</table>

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<tr>
<th>$VH(bb)$, 8 TeV</th>
<th>$\sigma$(stat)</th>
<th>$\sigma$(sys)</th>
<th>$\sigma$(theo)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$VH$, 0 lepton</td>
<td>$\pm 0.5$</td>
<td>$\pm 0.4$</td>
<td>$\pm 0.3$</td>
</tr>
<tr>
<td>$VH$, 1 lepton</td>
<td>$\pm 0.8$</td>
<td>$\pm 0.8$</td>
<td>$\pm 1.2$</td>
</tr>
<tr>
<td>$VH$, 2 leptons</td>
<td>$\pm 1.2$</td>
<td>$\pm 1.2$</td>
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</tbody>
</table>

### Comb. $VH(bb)$

<table>
<thead>
<tr>
<th>$\mu$ (Combined)</th>
<th>$\pm 0.2$</th>
<th>$\pm 0.1$</th>
<th>$\pm 0.1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$VH$, 0 lepton</td>
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<td>$\pm 1.2$</td>
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<td>$\pm 1.2$</td>
</tr>
</tbody>
</table>

### CMS Preliminary

- $m_H = 125$ GeV

<table>
<thead>
<tr>
<th>Process</th>
<th>$\mu$</th>
<th>$\pm 0.2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z(vv)H(bb)$</td>
<td>$\mu = 1.04 \pm 0.77$</td>
<td></td>
</tr>
<tr>
<td>$Z(t\bar{t})H(bb)$</td>
<td>$\mu = 0.82 \pm 0.97$</td>
<td></td>
</tr>
<tr>
<td>$W(\nu)H(bb)$</td>
<td>$\mu = 1.11 \pm 0.87$</td>
<td></td>
</tr>
</tbody>
</table>

### Signal strength

<table>
<thead>
<tr>
<th>$\sqrt{s}$, L</th>
<th>Signal strength $[\mu]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 TeV, $L = 4.7$ fb$^{-1}$</td>
<td>$\sigma / \sigma_{SM}$</td>
</tr>
<tr>
<td>8 TeV, $L = 20.3$ fb$^{-1}$</td>
<td>$\sigma / \sigma_{SM}$</td>
</tr>
</tbody>
</table>
Vector boson fusion production

1. Analysis strategy: look at $qqbb$ final state
   - Dedicated 4jets triggers exploiting VBF topology (high $\Delta \eta_{jj}$)
   - Select 2 forward jets with high $m_{jj}$ also specific to the VBF production
   - Apply b-tagging criteria for the non forward jets
   - Discrimination of quark/gluon jets (different fragmentation)

2. Main background: QCD production of 4 jets events

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Signal extraction:
Categories based in BDT (VBF tagging jets, b-tagging)
Then look at $m_{bb}$ distribution.
Combine categories.
Higgs boson searches in fermionic final state at LHC

Search for $H \rightarrow bb$ decay

**Signal extraction:**
Categories based in BDT (VBF tagging jets, b-tagging)
Then look at $m_{bb}$ distribution.
Combine categories.

$m_{bb}$ distribution and result:

@125 GeV
- exp : 3.0
- obs : 3.6
Overview

1. Search for $H \rightarrow bb$ decay

2. **Search for $H \rightarrow \tau\tau$ decay**

3. Search for $H \rightarrow \mu\mu$ decay

4. Dedicated searches for $ttH$ production
Search for $H \rightarrow \tau\tau$

**Which production mode?** All of them are exploited

- Mostly sensitive for high $p_T(\tau,\tau)$
- Tagging jets most sensitive
- Lower rate, less sensitive
- Dedicated search, see later

References:
- ATLAS-CONF-2012-160
- CMS PAS HIG-13-004, CMS PAS HIG-12-053
Search for $H \rightarrow \tau\tau$

Which production mode? All of them are exploited

- mostly sensitive for high $p_T(\tau, \tau)$
- tagging jets most sensitive
- lower rate, less sensitive
- dedicated search, see later

Experimental challenges for $H \rightarrow \tau\tau$:

- Decay of $\tau$ pair into stable particles leads to 3 different final states
- Reconstruction of $(\tau, \tau)$ invariant mass (escaping neutrinos)
- Energy scale determination of hadronic $\tau$ decays (and its uncertainty)

References: ATLAS-CONF-2012-160, CMS PAS HIG-13-004, CMS PAS HIG-12-053
Higgs boson searches in fermionic final state at LHC

Search for $H \rightarrow \tau\tau$ decay

- **High BR, 2 $\nu$'s, high MJ bkg (fakes), $\tau$-based trigger**
- **Low BR, 4 $\nu$'s, very clean signature, lep-based trigger**
- **High BR, 3 $\nu$'s, clean signature ($W$+jets as bkg), lep & $\tau$-based trigger**
Higgs boson searches in fermionic final state at LHC

Search for $H \rightarrow \tau\tau$ decay

**high BR, 2 v's,**
high MJ bkg (fakes),
$\tau$-based trigger

**low BR, 4 v's,**
very clean signature,
lep-based trigger

**high BR, 3 v's,**
$\sim$clean signature
(W+jets as bkg),
lep & $\tau$-based trigger

---

**CMS Simulation** $\sqrt{s} = 8$ TeV

$H \rightarrow \tau\tau$ $m_H = 125$ GeV

$Z \rightarrow \tau\tau$

Assess v's kinem: better H/Z separation.
$\sim 25\%$ gain on sensitivity

**ATLAS** Preliminary

$\sqrt{s} = 8$ TeV

1 prong
0.8<$|\eta|<$1.3

energy response controlled at $<5\%$

---

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Higgs boson searches in fermionic final state at LHC

Search for $H \to \tau\tau$ decay

Common strategy:

- Search for a bump in $m_{\tau\tau}$ on top of dominant background: $Z \to \tau\tau$
- Data-driven estimation of $Z \to \tau\tau$: use $Z \to \mu\mu$ data events with $\mu$ pair replaced by simulated $\tau$ pair (non-\tau quantities are data).
- Exploit VBF via di-jet topology ($\text{high } \Delta\eta_{jj}, \text{high } m_{jj}$)
- Exploit GGF at high ($\tau, \tau$) boost: better RMS($E_T$) $\to$ better RMS($m_{\tau\tau}$)
- Reduce and understand the fake $\tau$s (see next slide)
Higgs boson searches in fermionic final state at LHC

Search for $H \rightarrow \tau\tau$ decay

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Higgs boson searches in fermionic final state at LHC

Search for $H \to \tau\tau$ decay

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Reduces contribution from
* Top bkg (true leptons)
* W+jets bkg (fake lepton)
(used in CMS)

ATLAS uses same kinematic properties slightly differently

$D_\zeta \equiv \rho_\zeta - 0.85 \cdot p^\text{vis}_\zeta$

In $\tau_h \tau_h$ channel:
Multi-jets contribution estimated via a fit on data based on 2D templates
(used in ATLAS)

CMS uses an anti-isolated $\tau$ to estimate this background
$m_{\tau\tau}$ distribution

![Graphs showing $m_{\tau\tau}$ distributions for different categories and processes.](image)
Results: exclusion limit

<table>
<thead>
<tr>
<th>CMS Preliminary, √s=7-8 TeV, L = 24.3 fb⁻¹, H → ττ</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Graph showing 95% CL limit on σ/σ_{SM}" /></td>
</tr>
<tr>
<td>@125 GeV</td>
</tr>
<tr>
<td>- exp : 0.77</td>
</tr>
<tr>
<td>- obs : 1.81</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ATLAS Preliminary</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image2.png" alt="Graph showing 95% CL limit on σ/σ_{SM}" /></td>
</tr>
<tr>
<td>@125 GeV</td>
</tr>
<tr>
<td>- exp : 1.2</td>
</tr>
<tr>
<td>- obs : 1.9</td>
</tr>
</tbody>
</table>
Results: compatibility with background only
Higgs boson searches in fermionic final state at LHC

Search for $H \rightarrow \tau \tau$ decay

Some highlights:

- **2.85 $\sigma$ excess** for CMS, compatible with $H \rightarrow \tau \tau$ SM process
- ATLAS needs to add remaining 8 TeV data
- **CMS $bb + \tau \tau$ combination** leads to **3.4 $\sigma$ excess** fermionic decay
- Start to probe Higgs field properties in fermionic final state
Associated production $VH$

Higgs boson searches in fermionic final state at LHC
Search for $H \rightarrow \tau\tau$ decay

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Higgs boson searches in fermionic final state at LHC

Search for \( H \rightarrow \tau \tau \) decay

Associated production \( VH \)
Higgs boson searches in fermionic final state at LHC
Search for $H \to \tau\tau$ decay

Associated production $VH$
Overview

1. Search for $H \rightarrow bb$ decay

2. Search for $H \rightarrow \tau\tau$ decay

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**Higgs boson searches in fermionic final state at LHC**

Search for $H \rightarrow \mu\mu$ decay

**H $\rightarrow \mu\mu$ : motivations, challenges, strategy**

1. **Motivations**:
   - Directly sensitive to $g_{H\mu\mu}$,
   - $\mathcal{BR}_{H\rightarrow\mu\mu} \sim 2.2 \cdot 10^{-4}$: small but enhanced in some BSM scenarios,
   - **Clear signature**: bump in $M_{\mu\mu}$ distribution.

2. **Challenges**:
   - Important background: $Z \rightarrow \mu\mu$ with $s/p_{b} = 0.26$ (for 20 fb$^{-1}$),
   - Key instrumental feature: $M_{\mu\mu}$ resolution.

3. **Strategy**:
   - Look for a bump between 110–150 GeV $M_{\mu\mu}$
   - Split events in 2 categories based on $M_{\mu\mu}$ resolution,
   - Bkg/signal modelling: analytical shapes (fit in MC), unbinned fit
Higgs boson searches in fermionic final state at LHC
Search for $H \rightarrow \mu\mu$ decay

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Higgs boson searches in fermionic final state at LHC
Search for $H \rightarrow \mu\mu$ decay

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References : ATLAS-CONF-2013-010
Higgs boson searches in fermionic final state at LHC

Search for $H \rightarrow \mu\mu$ decay

**ATLAS Preliminary**

Simulation

- Central
  - $m_W = 125$ GeV
  - $\sigma_{CB} = 2.3$ GeV
  - FWHM = 4.9 GeV

**ATLAS Preliminary**

$\tilde{s} = 8$ TeV, $Ldt = 20.7$ fb$^{-1}$

$H \rightarrow \mu^+\mu^-$

95% CL Limit on $\mu$

- Observed
- Bkg. Expected
- $\pm 1 \sigma$
- $\pm 2 \sigma$

Local $p_0$

- Observed
- Sig. Expected

$\tilde{s} = 8$ TeV

H"{o}nman Madar (Freiburg University)
Overview

1. Search for $H \rightarrow bb$ decay
2. Search for $H \rightarrow \tau\tau$ decay
3. Search for $H \rightarrow \mu\mu$ decay
4. Dedicated searches for $ttH$ production
Direct access to couplings between Higgs and top quark field:

- Test proportionality between mass and couplings
- Higgs field properties at higher mass scale - new physics might appear
- Constrain potential new physics appearing in loops
Higgs boson searches in fermionic final state at LHC
Dedicated searches for $ttH$ production

**Direct access to couplings between Higgs and top quark field:**
- Test *proportionality* between mass and couplings
- Higgs field properties at **higher mass scale** - new physics might appear
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\[ \sigma(gg \rightarrow H) \propto \]

- can be measured
- known if Higgs-Top coupling are measured
- we don't know!
Dedicated searches for $ttH$ production

Direct access to couplings between Higgs and top quark field:

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Extremely challenging:

- Low production rate: $0.4\%$ of $\sigma_{\text{tot}}(H)$.
- Complex final state: leptons, 4 $b$-jets (combinatorics), $E_T$, potentially $\tau$s
- Large background systematics ($t\bar{t} + b$-jets, $t\bar{t} + V$).

References: ATLAS-CONF-2012-135, CMS PAS HIG-13-019
Higgs boson searches in fermionic final state at LHC
Dedicated searches for $ttH$ production

Strategy adopted by ATLAS:

- Focus on $H \rightarrow bb$ decay and $t\bar{t}$ semi-leptonic decay
- *Not presented*: $ttH(\rightarrow \gamma\gamma)$
- Kinematic reconstruction and $b$-jets pairing: global fit event-by-event

Common to ATLAS & CMS: fit data in several categories to reduce systematics on $t\bar{t} + b$-jets / $t\bar{t} + V$ backgrounds
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**Pre-fit**

- Data (1 fb⁻¹) vs MC (1 fb⁻¹)
- \( \ell + \mu \geq 6 \) jets, \( \geq 4 \) b tags
- \( t\bar{t} \)
- \( t\bar{t}V \)
- \( W + \) jets
- \( Z + \) jets
- Diboson
- Single top
- Multijet
- Total background uncertainty

**Post-fit**

- Data (1 fb⁻¹) vs MC (1 fb⁻¹)
- \( \ell + \mu \geq 6 \) jets, \( \geq 4 \) b tags
- \( t\bar{t}H \) (125)
- \( t\bar{t} \)
- \( t\bar{t}V \)
- \( W + \) jets
- \( Z + \) jets
- Diboson
- Single top
- Multijet
- Total background uncertainty

**ATLAS Preliminary**

- Observed (CLs)
- Expected (CLs)

\( 95\% \) CL Limit on \( \sigma / \sigma_{SM} \)

@125 GeV
- exp : 10.5
- obs : 13.1
Higgs boson searches in fermionic final state at LHC

Dedicated searches for $ttH$ production

**Strategy adopted by CMS:**

- Exploit $H \rightarrow bb$ and $H \rightarrow \tau\tau$ decays. Not presented: $ttH(\rightarrow \gamma\gamma)$.
- Make advantage of semi-leptonic and di-leptonic decays of $t\bar{t}$ system
- Combine b-tagging, $\tau$ID, $b$-jet pairing in a BDT for bkg/sig separation
- *Not presented:* $ttH(\rightarrow \gamma\gamma)$ and its full combination with $ttH(\rightarrow bb/\tau\tau)$
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Higgs boson searches in fermionic final state at LHC

Dedicated searches for $ttH$ production

Romain Madar (Freiburg University)
Higgs fermonic decays are experimentally challenging:
low production rate, high background, complicated final state
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Crucial searches to fully understand the sector of the new boson:

- Direct measurement of coupling to fermionic fields
- Crucial for the new boson properties measurement (*talk by E. Pianori*)

Reach SM sensitivity in the key channels (3-4 σ excess in \( tt\bar{b}b \) at CMS), and more to come with refined analysis and/or more data.

Essential step toward new physics discovery: \( ttH \) and \( GGF/VBF \) offer a unique way of probing new physics in Higgs sector.

Sensitivity to \( BR(H \rightarrow inv) \) is dominated by \( G(H \rightarrow bb) \) uncertainty.
Higgs fermonic decays are experimentally challenging: low production rate, high background, complicated final state

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Wide search program at LHC and first exciting results:
- Golden channels: VH($\rightarrow bb$) & GGF/VBF H→ $\tau\tau$
- Secondary channels: ttH, VH($\rightarrow \tau\tau$), VBF H→ $bb$
- Reach SM sensitivity in the key channels ($3.4\sigma$ excess in $\tau\tau + bb$ at CMS), and more to come with refined analysis and/or more data
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Essential step toward new physics discovery:
- $ttH$ and GGF offer a unique way of probing new physics in Higgs sector
- Sensitivity to $BR(H \rightarrow inv)$ is dominated by $\Gamma(H \rightarrow bb)$ uncertainty