Bestimmung der Higgsboson-Kopplungen
im und jenseits des Standardmodells

Michael Rauch | 29. März 2011
Higgs production modes

Main Higgs-boson production modes:

- gluon-gluon fusion
- vector-boson fusion
- associated production with gauge bosons
- associated production with top-quark–antiquark pair
Higgs decay modes

- $H \rightarrow b\bar{b}$
  - main decay mode ($\sim 90\%$) for light Higgs bosons, as suggested by electroweak precision data
  - hard to extract from QCD backgrounds
  - recent suggestion of $WH/ZH$ production plus jet substructure analysis looks promising
    (3.7$\sigma$ @ 30 fb$^{-1}$ & 14 TeV)
    [Butterworth, Davison, Rubin, Salam; ATL-PHYS-PUB-088]

- $H \rightarrow \tau\bar{\tau}$
  - need to reconstruct invariant mass of the two taus
  - limits production channel to vector-boson fusion
  - one of the discovery channels for light Higgs bosons
    [Plehn, Rainwater, Zeppenfeld]

- $H \rightarrow WW$
- $H \rightarrow ZZ$
- $H \rightarrow \gamma\gamma$
Higgs decay modes

- $H \rightarrow b\bar{b}$
- $H \rightarrow \tau\bar{\tau}$
- $H \rightarrow WW$
  - main decay mode for heavier Higgs bosons ($m_H \gtrsim 140$ GeV)
  - gluon and vector-boson fusion relevant even if $W$s are off-shell
- $H \rightarrow ZZ$
  - “Golden Channel” due to four-lepton final state
  - statistically limited to larger Higgs masses
- $H \rightarrow \gamma\gamma$
Higgs decay modes

- $H \rightarrow b\bar{b}$
- $H \rightarrow \tau\bar{\tau}$
- $H \rightarrow WW$
- $H \rightarrow ZZ$
- $H \rightarrow \gamma\gamma$

- Loop-induced coupling by (mainly) $W$ and $t$
- Only fully reconstructable channel for a light Higgs boson
- Small branching ratio ($\lesssim 0.2\%$)
- Promising discovery channel for light Higgs bosons, background can be subtracted via sidebands
- Higgs mass measurement up to 100 MeV
Higgs properties

Verify that observed resonance is “Higgs”

- spin-0 particle
  - spin-1 excluded by $H \rightarrow \gamma\gamma$
  - spin-2: look at angular correlations

- CP-nature
  - SM-Higgs CP-even; extended Higgs sectors also CP-odd or mixed states
  - look at angular correlations

- couplings
  - unitarity in $W_L W_L \rightarrow W_L W_L$ scattering
    - fixed coupling $g_{WWW} \propto m_W$
  - fermion masses
    - $g_{fH} \propto m_f$
  - Higgs self-couplings
    - determine shape of Higgs potential via trilinear and quartic couplings
    - SM: $V = \mu^2 |\Phi|^2 + \lambda |\Phi|^4 + \text{const.}$
    - new scale $\Lambda$: $V = \sum_{n \geq 0} \frac{\lambda^n}{\Lambda^{2n}} \left( |\Phi|^2 + \frac{v^2}{2} \right)^{2+n}$
    - very challenging for LHC

[Landau-Yang theorem]
[Hagiwara, Mawatari, Li; Frank, MR, Zeppenfeld]
[Choi, Eberle, Miller, Mühlleitner, Zerwas]
[Englert, Hackstein, Spannowsky] → T13.4

[Choi, Eberle, Miller, Mühlleitner, Zerwas]

[Englert, Hackstein, Spannowsky] → T18.3

[Plehn et al.; Baur et al.; MR et al.; Binoth et al.; ...]
**Generalized Higgs sector**

How well can we determine the SM Higgs couplings? Can we distinguish a non-Standard-Model-like Higgs sector?

- **Theory:** Standard Model plus general Higgs sector
- **For Higgs couplings present in the Standard Model** \( j = W, Z, t, b, \tau \)
  
  replace general couplings by
  
  \[
  g_{jjH} \longrightarrow g_{jjH}^{\text{SM}} \left( 1 + \Delta_{jjH} \right) \quad (\rightarrow \Delta = -2 \text{ means sign flip})
  \]
- **For loop-induced Higgs couplings** \( j = \gamma, g \)
  
  replace by
  
  \[
  g_{jjH} \longrightarrow g_{jjH}^{\text{SM}} \left( 1 + \Delta_{jjH}^{\text{SM}} + \Delta_{jjH} \right)
  \]

  where
  
  - \( g_{jjH}^{\text{SM}} \): (loop-induced) coupling in the Standard Model
  - \( \Delta_{jjH}^{\text{SM}} \): contribution from modified tree-level couplings to Standard-Model particles
  - \( \Delta_{jjH} \): additional (dimension-five) contribution

- **Additional free parameters:**
  - Higgs boson mass \( m_H \)
  - top- and bottom-quark mass \( m_t, m_b \)

- **Neglecting couplings only available from high-luminosity analyses**
  
  \( (g_{H\mu\mu}, g_{HZZ\gamma}, g_{HHH}, g_{HHHH}) \)
Higgs at the LHC

Zeppenfeld, Kinnunen, Nikitenko, Richter-Was; Dührssen et al.

<table>
<thead>
<tr>
<th>production</th>
<th>decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>$gg \to H$</td>
<td>ZZ</td>
</tr>
<tr>
<td>$qqH$</td>
<td>ZZ</td>
</tr>
<tr>
<td>$gg \to H$</td>
<td>$WW$</td>
</tr>
<tr>
<td>$qqH$</td>
<td>$WW$</td>
</tr>
<tr>
<td>$t\bar{t}H$</td>
<td>$WW(3\ell)$</td>
</tr>
<tr>
<td>$\bar{t}tH$</td>
<td>$WW(2\ell)$</td>
</tr>
<tr>
<td>inclusive</td>
<td>$\gamma\gamma$</td>
</tr>
<tr>
<td>$qqH$</td>
<td>$\gamma\gamma$</td>
</tr>
<tr>
<td>$t\bar{t}H$</td>
<td>$\gamma\gamma$</td>
</tr>
<tr>
<td>$WH$</td>
<td>$\gamma\gamma$</td>
</tr>
<tr>
<td>$ZH$</td>
<td>$\gamma\gamma$</td>
</tr>
<tr>
<td>$qqH$</td>
<td>$\tau\tau(2\ell)$</td>
</tr>
<tr>
<td>$qqH$</td>
<td>$\tau\tau(1\ell)$</td>
</tr>
<tr>
<td>$t\bar{t}H$</td>
<td>$b\bar{b}$</td>
</tr>
</tbody>
</table>

| WH/ZH       | $bb$ (subjet) |

Total width

- degeneracy $\sigma \cdot BR \propto g_p^2 \frac{g_d^2}{\Gamma_H}$ \((\Gamma_H \propto g^2)\)
- Here: $\Gamma_H = \sum_{SM} \Gamma_i$

\[ \Delta g^2(H,X) \]
### Higgs at the LHC

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<tr>
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<td>$WW$</td>
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</tr>
<tr>
<td>$t\bar{t}H$</td>
<td>$\gamma\gamma$</td>
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<tr>
<td>$WH$</td>
<td>$\gamma\gamma$</td>
</tr>
<tr>
<td>$ZH$</td>
<td>$\gamma\gamma$</td>
</tr>
<tr>
<td>$qqH$</td>
<td>$\tau\tau(2\ell)$</td>
</tr>
<tr>
<td>$qqH$</td>
<td>$\tau\tau(1\ell)$</td>
</tr>
<tr>
<td>$ttH$</td>
<td>$b\bar{b}$ (subj)</td>
</tr>
</tbody>
</table>

**Total width**

- degeneracy $\sigma \cdot BR \propto g_p^2 g_d^2 \Gamma_H (\Gamma_H \propto g^2)$
- Here: $\Gamma_H = \Sigma_{SM} \Gamma_i$

[Lafaye, Plehn, MR, Zerwas, Dührssen 2009]
Error analysis

Errors obtained by 10,000 toy experiments:
SM hypothesis, \( m_H = 120 \text{ GeV} \), \( \mathcal{L} = 30 \text{ fb}^{-1} \)
Fit with Gaussian of the central part within one standard deviation

<table>
<thead>
<tr>
<th>no eff. couplings</th>
<th>with eff. couplings</th>
<th>ratio ( \Delta_{jjH/WWH} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{\text{symm}} )</td>
<td>( \sigma_{\text{symm}} )</td>
<td>( \sigma_{\text{symm}} )</td>
</tr>
<tr>
<td>( \sigma_{\text{neg}} )</td>
<td>( \sigma_{\text{neg}} )</td>
<td>( \sigma_{\text{neg}} )</td>
</tr>
<tr>
<td>( \sigma_{\text{pos}} )</td>
<td>( \sigma_{\text{pos}} )</td>
<td>( \sigma_{\text{pos}} )</td>
</tr>
</tbody>
</table>

\( \Delta_{WWH} \) ± 0.23 \( ± 0.24 \)
\( \Delta_{ZZH} \) ± 0.36 \( ± 0.31 \)
\( \Delta_{ttH} \) ± 0.41 \( ± 0.53 \)
\( \Delta_{bbH} \) ± 0.45 \( ± 0.44 \)
\( \Delta_{\tau\tau H} \) ± 0.33 \( ± 0.31 \)
\( \Delta_{\gamma\gamma H} \) — \( ± 0.31 \)
\( \Delta_{ggH} \) — \( ± 0.61 \)

\( \mathcal{L} = 30 \text{ fb}^{-1} \)
with eff. couplings
SM hypothesis

Analysis performed with SFitter
[Lafaye, Plehn, MR, Zerwas]
Invisible vs. Unobserved

- Invisible Higgs decays actually observable
  - Vector-Boson Fusion: tagging jets plus missing $E_T$ [Eboli, Zeppenfeld]
  - $WH/ZH$: recoil against nothing [Choudhury, Roy; Godbole, Guchait, Mazumdar, Moretti, Roy]

- Unobservable decays into particles with large backgrounds (like $H \rightarrow$ jets)
  e.g. increased $ccH$ coupling (corresponding to 15.4 GeV Yukawa coupling)
Invisible vs. Unobserved

- Unobservable decays into particles with large backgrounds (like $H \rightarrow \text{jets}$)
  - e.g. increased $ccH$ coupling (corresponding to 15.4 GeV Yukawa coupling)
  - $\mathcal{L} = 30 \text{ fb}^{-1}$, SM data / increased $ccH$ / increased $ccH$ plus free width

\[
1/\chi^2
\]

\[
\Delta_{WWH}, \Delta_{ttH}, \Delta_{ggH}
\]

\[
\Delta_{\Gamma}
\]

\[
\text{free width only}
\]

Yc

SM 5.4 50 100

$\Delta_{\Gamma}$
The Higgs Portal

Additional hidden sector as singlet under SM gauge groups

Only possible connection to SM:
\[ \mathcal{L} \propto \Phi_s^\dagger \Phi_s \Phi_h^\dagger \Phi_h \]

\( \Phi_{s/h} \): Higgs field of SM/hidden sector

Electro-weak symmetry breaking:
\[ \phi_{s/h} \rightarrow (v_{s/h} + H_{s/h})/\sqrt{2} \]

Higgs fields of SM/hidden sector mix:
\[ H_s \text{ and } H_h \text{ mix into mass eigenstates:} \]
\[ \begin{pmatrix} H_1 \\ H_2 \end{pmatrix} = \begin{pmatrix} \cos \chi & \sin \chi \\ -\sin \chi & \cos \chi \end{pmatrix} \begin{pmatrix} H_s \\ H_h \end{pmatrix} \]

\[ \sigma = \cos^2 \chi \cdot \sigma^{\text{SM}} \]
\[ \Gamma_{\text{vis}} = \cos^2 \chi \cdot \Gamma_{\text{vis}}^{\text{SM}} \]
\[ \Gamma_{\text{inv}} = \cos^2 \chi \cdot \Gamma_{\text{inv}}^{\text{SM}} + \Gamma_{\text{hid}} \]

\( \begin{align*}
\Gamma^{\text{SM}}_{\text{inv}}: \text{Decay } H \rightarrow ZZ \rightarrow 4\nu \text{ (negligible)}
\end{align*} \)
The Higgs Portal

Fit of $\cos^2 \chi_{\text{fit}}$ without constraints

- No invisible decay modes
  $$\cos^2 \chi_{\text{th}} = 1.0$$

$$\Rightarrow$$ If $\cos^2 \chi_{\text{th}} < 0.6$ can exclude SM at the 95% CL with 30 fb$^{-1}$

- Measuring invisible decays in VBF-Higgs production
  Signature: Two VBF-jets plus missing $E_T$
  $$\Gamma_{\text{hid}} = \sin^2 \chi \cdot \Gamma_{\text{tot}}^{\text{SM}}$$  (rhs: $\cos^2 \chi_{\text{th}} = 0.6$)
Observation Bias

Significant backgrounds in Higgs measurement channels

- Measure signal plus background in signal region
- Extrapolate background from signal-free control regions (sidebands, etc.) and subtract
- Background from theory typically not better
- ⇒ B from control regions can be larger than S+B in signal region

positive number of signal events

\[ S > 2 \Delta S \]
for nominal SM rate

\[ S > 2 \Delta S \]
for actual rate

⇒ Careful treatment necessary
Observation of Higgs bosons favors larger couplings
Cross-check using all predicted channels
Strongly-Interacting Light Higgs

Higgs pseudo-Goldstone boson of new strongly interacting sector
Modifications parametrized by $\xi = (v/f)^2$ \hspace{1cm} (f: Goldstone scale)

- **MCHM4:**
  Scaling of all couplings with $\sqrt{1 - \xi}$
  $\Rightarrow$ Identify $\cos^2 \chi = 1 - \xi$
  $\Gamma_{hid} = 0$

- **MCHM5:**
  Scaling:
  $g_{VVH} = g_{VVH}^{\text{SM}} \cdot \sqrt{1 - \xi}$
  $g_{fH} = g_{fH}^{\text{SM}} \cdot \frac{1 - 2\xi}{\sqrt{1 - \xi}}$

Significant and observable deviations also in Higgs self-couplings

[Giudice, Grojean, Pomarol, Rattazzi; Espinosa, Grojean, Mühlleitner]

[Gröber, Mühlleitner] → T18.6
Secondary solutions appear (sign of $\bar{f}fH$ coupling)

$m_H = 120$ GeV

$m_H = 160$ GeV

$m_H = 200$ GeV

$\mathcal{L} = 300$ fb$^{-1}$

Gluon fusion $H \rightarrow \gamma\gamma$

$WH/ZH$, $H \rightarrow b\bar{b}$

Not a true degeneracy

$\rightarrow$ Each (smeared) toy experiment has unique solution
Conclusions

- Determining the Higgs-boson couplings next step after discovery
  Important for our understanding of electroweak symmetry breaking
- Independent of explicit realisation of new physics (if any):
  Standard Model with effective Higgs couplings
- Expected accuracy of 20 – 50% in Standard Model at 30 fb\(^{-1}\)
- Recent jet substructure analysis significantly improves
  result on bottom-quark coupling
- Influences accuracy of all other couplings via total width
- Extended Models (Portal Higgs, SILH) can lead to simple one-parameter
  deviations which can be tested
- Beware of observation bias and degenerate solutions
need to scan high-dimensional parameter space

⇒ SFitter

General Higgs couplings from modified version of HDecay

Three scanning techniques:
- Weighted Markov Chain
- Cooling Markov Chain (equivalent to simulated annealing)
- Gradient Minimisation (Minuit)

Output of SFitter:
- Fully-dimensional log-likelihood map
- Reduction to plotable one- or two-dimensional distributions via both
  - Bayesian (marginalisation) or
  - Frequentist (profile likelihood) techniques
- List of best points

Already successfully used for SUSY parameter extraction study

[EPJC 54(2008) [arXiv:0709.3985]]
Discovering the Higgs boson

Tevatron results

Prospects for 7 and 8 TeV
### Higgs at the LHC

**Input data**  [Dührssen (ATL-PHYS-2002-030), ATLAS CSC Note; CMS results comparable]

\[ m_H = 120 \text{ GeV}; \quad \mathcal{L} = 30 \text{ fb}^{-1} \]

<table>
<thead>
<tr>
<th>production</th>
<th>decay</th>
<th>( S + B )</th>
<th>( B )</th>
<th>( S )</th>
<th>( \Delta S^{(\text{exp})} )</th>
<th>( \Delta S^{(\text{theo})} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( gg \rightarrow H )</td>
<td>( ZZ )</td>
<td>13.4</td>
<td>6.6 (( \times 5 ))</td>
<td>6.8</td>
<td>3.9</td>
<td>0.8</td>
</tr>
<tr>
<td>( qqH )</td>
<td>( ZZ )</td>
<td>1.0</td>
<td>0.2 (( \times 5 ))</td>
<td>0.8</td>
<td>1.0</td>
<td>0.1</td>
</tr>
<tr>
<td>( gg \rightarrow H )</td>
<td>( WW )</td>
<td>1019.5</td>
<td>882.8 (( \times 1 ))</td>
<td>136.7</td>
<td>63.4</td>
<td>18.2</td>
</tr>
<tr>
<td>( qqH )</td>
<td>( WW )</td>
<td>59.4</td>
<td>37.5 (( \times 1 ))</td>
<td>21.9</td>
<td>10.2</td>
<td>1.7</td>
</tr>
<tr>
<td>( t\bar{t}H )</td>
<td>( WW(3\ell) )</td>
<td>23.9</td>
<td>21.2 (( \times 1 ))</td>
<td>2.7</td>
<td>6.8</td>
<td>0.4</td>
</tr>
<tr>
<td>( t\bar{t}H )</td>
<td>( WW(2\ell) )</td>
<td>24.0</td>
<td>19.6 (( \times 1 ))</td>
<td>4.4</td>
<td>6.7</td>
<td>0.6</td>
</tr>
<tr>
<td>inclusive</td>
<td>( \gamma\gamma )</td>
<td>12205.0</td>
<td>11820.0 (( \times 10 ))</td>
<td>385.0</td>
<td>164.9</td>
<td>44.5</td>
</tr>
<tr>
<td>( qqH )</td>
<td>( \gamma\gamma )</td>
<td>38.7</td>
<td>26.7 (( \times 10 ))</td>
<td>12.0</td>
<td>6.5</td>
<td>0.9</td>
</tr>
<tr>
<td>( t\bar{t}H )</td>
<td>( \gamma\gamma )</td>
<td>2.1</td>
<td>0.4 (( \times 10 ))</td>
<td>1.7</td>
<td>1.5</td>
<td>0.2</td>
</tr>
<tr>
<td>( WH )</td>
<td>( \gamma\gamma )</td>
<td>2.4</td>
<td>0.4 (( \times 10 ))</td>
<td>2.0</td>
<td>1.6</td>
<td>0.1</td>
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<tr>
<td>( ZH )</td>
<td>( \gamma\gamma )</td>
<td>1.1</td>
<td>0.7 (( \times 10 ))</td>
<td>0.4</td>
<td>1.1</td>
<td>0.1</td>
</tr>
<tr>
<td>( qqH )</td>
<td>( \tau\tau(2\ell) )</td>
<td>26.3</td>
<td>10.2 (( \times 2 ))</td>
<td>16.1</td>
<td>5.8</td>
<td>1.2</td>
</tr>
<tr>
<td>( qqH )</td>
<td>( \tau\tau(1\ell) )</td>
<td>29.6</td>
<td>11.6 (( \times 2 ))</td>
<td>18.0</td>
<td>6.6</td>
<td>1.3</td>
</tr>
<tr>
<td>( t\bar{t}H )</td>
<td>( b\bar{b} )</td>
<td>244.5</td>
<td>219.0 (( \times 1 ))</td>
<td>25.5</td>
<td>31.2</td>
<td>3.6</td>
</tr>
<tr>
<td>( WH/ZH )</td>
<td>( b\bar{b} )</td>
<td>228.6</td>
<td>180.0 (( \times 1 ))</td>
<td>48.6</td>
<td>20.7</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Last line obtained using subjet techniques ( [Butterworth, Davison, Rubin, Salam]), theoretical results confirmed by ATLAS ( [ATL-PHYS-PUB-2009-088]) (stricter cuts, statistical significance basically unchanged)
Distribution of parameters

One-dimensional distributions
- Slow-falling distributions with single peaks prefer profile likelihood
- Higher luminosity qualitatively similar, quantitatively better
- Including effective couplings allows sign degeneracy for $ttH$ coupling
- Smearing the dataset does not change picture substantially either

True dataset, 30 fb$^{-1}$; Profile likelihood vs. Bayesian
Distribution of parameters

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- Slow-falling distributions with single peaks prefer profile likelihood
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True dataset, Profile likelihood; 30 fb$^{-1}$ vs. 300 fb$^{-1}$

![Distribution plots with histograms and axes labels]
Distribution of parameters

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- Slow-falling distributions with single peaks prefer profile likelihood
- Higher luminosity qualitatively similar, quantitatively better
- Including effective couplings allows sign degeneracy for $ttH$ coupling
- Smearing the dataset does not change picture substantially either

True dataset, Profile likelihood, 30 fb$^{-1}$; Without vs. including eff. couplings
Distribution of parameters

One-dimensional distributions

- Slow-falling distributions with single peaks prefer profile likelihood
- Higher luminosity qualitatively similar, quantitatively better
- Including effective couplings allows sign degeneracy for $ttH$ coupling
- Smearing the dataset does not change picture substantially either

Profile likelihood, 30 fb$^{-1}$; True vs. smeared dataset
Non-decoupling Supersymmetric Higgs

SPS1a-inspired scenario with
\[ t_\beta = 7, \ A_t = -1100 \text{ GeV}, \ m_A = 151 \text{ GeV}, \ m_{h^0} = 120 \text{ GeV} \]

LHC data set with \( \mathcal{L} = 30 \text{ fb}^{-1} \), Profile likelihood, True dataset

\[
\frac{1}{\Delta \chi^2} \quad \text{true: } -0.13 \quad -0.19 \quad 3.27 \quad 3.29 \quad -0.28 = \Delta
\]

Clear deviation from Standard Model:
\[ q(d_{\text{SUSY}}|m_{\text{SM}}) < q(d_{\text{SM}}|m_{\text{SM}}) : 77\% \text{ at } 90\% \text{ CL} \]

Favouring of new physics more difficult: only 4% better described by SUSY model

Strong correlation between \( \Delta_{bbH} \) and \( \Delta_{\tau\tau H} \) via total width

No upper limit on \( g_{bbH} \) as \( BR \approx 1 \) compatible with data
Fat Jets

- Decay into $b\bar{b}$ main channel for light Higgs ($\sim 80\%$)
- Suffers from large QCD backgrounds → Use high-$p_T$ region
  - Higgs and $W/Z$ more likely to be central, $Z \to \nu\bar{\nu}$ visible
  - $t\bar{t}$ kinematics cannot simulate background
  - Much smaller cross section ($1/20$ for $p_T(H) > 200$ GeV)
  - $R \gtrsim \frac{3m_H}{p_T}$: resolve one jet in 75% of cases

- Algorithm to find fat jet”:
  1. Start with high-$p_T$ jet (Cambridge/Aachen algorithm)
  2. Undo last stage of clustering (≡ reduce $R$): $J \to J_1, J_2$
  3. If $\max(m_1, m_2) \lesssim 0.67 m$, call this a mass drop
  4. Require $y_{12} = \frac{\min(p_{T1}^2, p_{T2}^2)}{m_{T12}^2} \Delta R_{12} \simeq \frac{\min(z_1, z_2)}{\max(z_1, z_2)} > 0.09$
  5. Require each subjet to have b-tag
  6. Filter the jet: Reconsider region of interest at smaller $R_{\text{filt}} = \min(0.3, R_{bb}/2)$
  7. Take 3 hardest subjets
Fat Jets in Higgs channels

- **WH/ZH**
  - [Butterworth, Davison, Rubin, Salam; ATLAS]
  - ATLAS $\mathcal{L} = 30 \text{ fb}^{-1}$, $m_H = 120$ GeV
  - Significance:
    - No systematics: 3.7
    - 15% systematics: 3.0

- **$\bar{t}tH$**
- **$H$ plus new physics (SUSY, ...)**

[Butterworth, Davison, Rubin, Salam; ATLAS]

[M. Rauch – Bestimmung der Higgsboson-Kopplungen im und jenseits des Standardmodells]

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Fat Jets in Higgs channels

**WH/ZH**

ATLAS $\mathcal{L} = 30$ fb$^{-1}$, $m_H = 120$ GeV

Significance:
- No systematics: 3.7
- 15% systematics: 3.0

$\tilde{t}\tilde{t}H$

$H$ plus new physics (SUSY, ...)

---

<table>
<thead>
<tr>
<th>$\mathcal{L} = 100$ fb$^{-1}$</th>
<th>$S$</th>
<th>$B$</th>
<th>$S/B$</th>
<th>$S/\sqrt{B}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_H = 115$ GeV</td>
<td>57</td>
<td>118</td>
<td>1/2.1</td>
<td>5.2</td>
</tr>
<tr>
<td>120 GeV</td>
<td>48</td>
<td>115</td>
<td>1/2.4</td>
<td>4.5</td>
</tr>
<tr>
<td>130 GeV</td>
<td>29</td>
<td>103</td>
<td>1/3.6</td>
<td>2.9</td>
</tr>
</tbody>
</table>

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M. Rauch – Bestimmung der Higgsboson-Kopplungen im und jenseits des Standardmodells

29. März 2011 21/22
Secondary solutions appear (sign of $\bar{t}tH$ coupling)

$m_H = 120$ GeV

$m_H = 160$ GeV

$m_H = 200$ GeV

$\mathcal{L} = 300$ fb$^{-1}$

Gluon fusion $H \to \gamma\gamma$

$WH/ZH$, $H \to b\bar{b}$

Not a true degeneracy

→ Each (smeared) toy experiment has unique solution
Secondary solutions appear (sign of $\bar{t}tH$ coupling)

$m_H = 120$ GeV  \hspace{2cm} m_H = 160$ GeV  \hspace{2cm} m_H = 200$ GeV

Independent fit of common vector and fermion couplings

$\xi_{\text{th}} = 0$  \hspace{2cm} $\xi_{\text{th}} = 0.2$  \hspace{2cm} $\xi_{\text{th}} = 0.6$

Not a true degeneracy
→ Each (smeared) toy experiment has unique solution