Light mass Higgs properties: couplings

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- Introduction
- How can we probe the couplings of the new state?
- Interim recommendations of the Light Mass Higgs Group
- Analysis of couplings beyond 2012: ongoing work
- Conclusions

Introduction

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Sounds obvious and easy, but

Coupling determination: theory issues

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  A coupling is not directly a physical observable; what is measured is $\sigma \times \mathrm{BR}$ (within acceptances), etc.
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  $\Rightarrow$ Need to specify a Lagrangian in order to define the meaning of coupling parameters

- Once (electroweak) higher-order corrections are taken into account, the Higgs couplings in the SM cannot be treated as free parameters

  $\Rightarrow$ Cannot "measure" the couplings directly from a comparison of SM predictions with the data

Coupling determination: experimental issues

- The experimental results that have been obtained for the various channels are not model-independent
  - Properties of the SM Higgs have been used for discriminating between signal and background
  - Need the SM to correct for acceptances and efficiencies

- The total Higgs width cannot be measured at the LHC without additional assumptions
  $\Rightarrow$ Can in general only determine ratios of couplings, not absolute coupling values

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- Assume same acceptances and efficiencies as in the SM?
- How to disentangle different production modes?

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Correlations?

Very useful for confronting theory predictions with experimental results

Widely used in the literature

Single channel results vs. simultaneous information from several channels

Adding information from different channels increases sensitivity

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But comparison of extracted couplings with “best” SM predictions (as defined by the LHCHXSWG, including higher-order corrections) is difficult

Is the chosen basis for the couplings sufficiently general to express the SM predoctions including all available higher-order corrections?

Strategy for the coupling analysis

As long as the SM continues to be (roughly) compatible with the data:

$\Rightarrow$ Use full SM predictions including all available higher-order corrections (“best” SM predictions as defined by the LHCHXSWG)

$+$ parametrisation of deviations

$\Rightarrow$ Appropriate tools needed

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In case SM gets ruled out $\Rightarrow$ Move to other reference model

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Deviations from the SM would in general change kinematic distributions

$\Rightarrow$ No simple rescaling of MC predictions possible

$\Rightarrow$ Not feasible for analysis of 2012 data set

$\Rightarrow$ Proposal of “interim framework”

Interim recommendations of the Light Mass Higgs Group

Recommendations of the LM subgroup of the LHC Higgs XS WG for analyses of 2012 data:

Assumptions:

- Signal corresponds to only one state, no overlapping resonances, etc.
- Zero-width approximation
- Only modifications of coupling strenghts (absolute values of the couplings) are considered, no modification of the tensor structure as compared to the SM case

  $\Rightarrow$ Assume that the observed state is a $\mathcal{CP}$-even scalar

Recommendations of the LM subgroup of the LHC Higgs XS WG for analyses of 2012 data

Use state-of-the-art predictions in the SM and rescale the predictions with "leading order inspired" scale factors κ_i ($\kappa_i = 1$ corresponds to the SM case)

Note: scaling of couplings is in general not possible if higher-order electroweak corrections are included

In the SM: Higgs sector is determined by single parameter M_{H} ($+$ higher-order contributions)

$\Rightarrow$ Once M_{H} is fixed the Higgs couplings are determined and cannot be varied within the SM

Recommendations of the LM subgroup of the LHC Higgs XS WG for analyses of 2012 data

Scaling of couplings $\Leftrightarrow$ test of deviations from the SM

Note: acceptances and efficiencies are assumed to be as in the SM

$\Rightarrow$ This will have an impact on the interpretation in case a sizable deviation from the SM prediction gets established

$\Rightarrow$ Results obtained from the analysis with scaled couplings cannot be interpreted as "coupling measurements"

Recommendations of the LM subgroup of the LHC Higgs XS WG for analyses of 2012 data

Which kind of scaling factors should be considered?

In general, scale factors are needed for couplings of the new state to

t, b, τ, W, Z, $\ldots$

$+$ extra loop contribution to $\sigma(gg \to H)$, $\Gamma(H \to gg)$

$+$ extra loop contribution to $\Gamma(H \to \gamma\gamma)$

$+$ additional contributions to total width, Γ_H, from undetectable final states

Total width Γ_H cannot be measured without further assumptions (otherwise only coupling ratios can be determined, not absolute values of couplings)

Proposed "benchmarks" for scale factors κ_i

Different "benchmark" proposals, based on simplifying assumptions to reduce the number of free parameters

1 parameter: overall coupling strength μ

2 parameters: e.g. common scale factor κ_V for W, Z, and common scale factor for all fermions, κ_F

. . .

For each benchmark (except overall coupling strength) two versions are proposed:

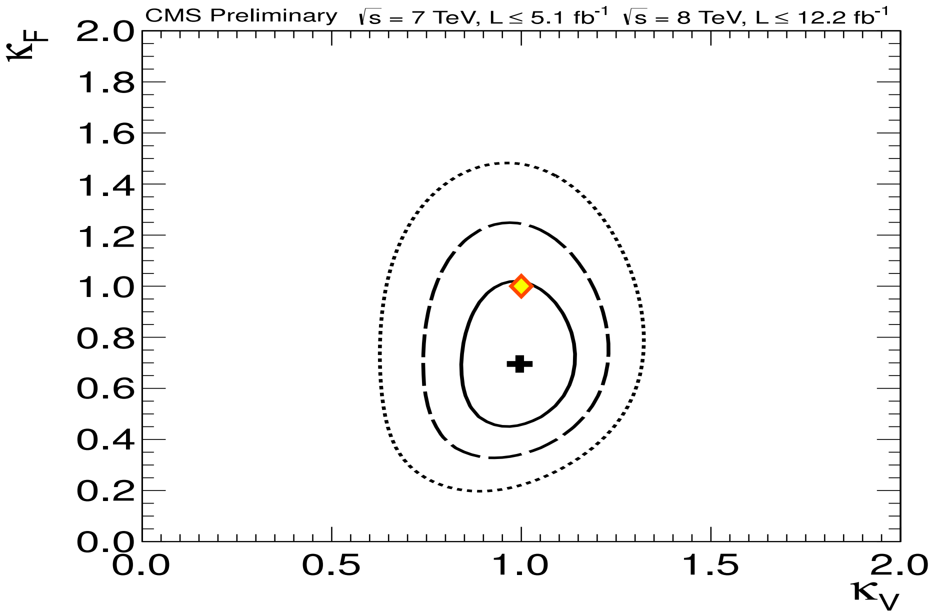
with and without taking into account the possibility of additional contributions to the total width

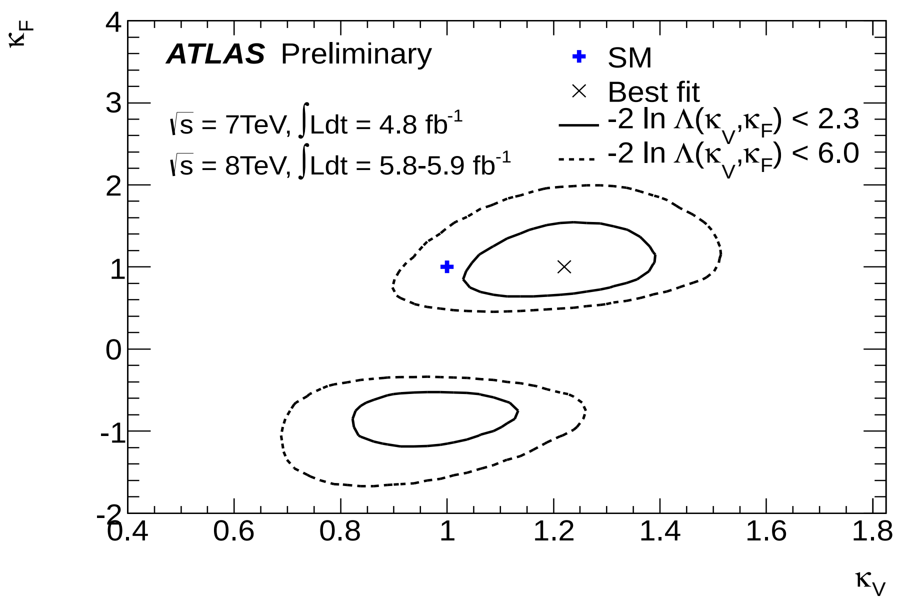
Proposed “benchmarks” for scale factors κ_i

If additional contributions to Γ_H are allowed
$\Rightarrow$ Determination of ratios of scaling factors, e.g. $\kappa_i \kappa_j / \kappa_H$

If no additional contributions to $\Gamma(H \to \gamma\gamma)$, Γ_H, $\ldots$ are allowed
$\Rightarrow$ κ_γ can be determined in terms of κ_b, κ_t, κ_τ, κ_W
evaluated to NLO QCD accuracy

Example: κ_V, κ_F analyses from CMS and ATLAS





MSSM interpretation of scale factors κ_i?

- Higgs couplings to up-type and down-type fremions are different $\Rightarrow$ cannot be described in terms of common κ_F
- Large SUSY contributions can affect relation between coupling to $b\bar{b}$ and $\tau^+\tau^-$
- Extra contributions to $\sigma(gg \to H)$, $\Gamma(H \to gg)$, $\Gamma(H \to \gamma\gamma)$: $\tilde{\mathrm{t}}$, $\tilde{\tau}$, $\tilde{\chi}^{\pm}$, ...
- Extra contribution to total width: $H \to$ invisible, ...

Would need a larger number of free parameters than the ones allowed in the benchmark scenarios

$\Rightarrow$ Benchmark scenarios of this kind are usually too restrictive to allow an interpretation within a "realistic" model like the MSSM

Analysis of couplings beyond 2012: ongoing work

Framework:

- Use “best” SM predictions (as defined by the LHCHXSWG) $+$ parametrisation of deviations
- Use effective Lagrangian for parametrisation of deviations

$\Rightarrow$ The tools that are used for obtaining the “best” SM predictions need to be extended to incorporate appropriate parametrisations of deviations from the SM

Which effective Lagrangian should be chosen?

- Should be sufficiently general so that the results can be interpreted in realistic models
  - One should not assume from the start that the new state is a $\mathcal{CP}$-even scalar
  - Consider both changes in the strength and the tensor structure of the couplings

  $\Rightarrow$ Analysis of couplings is directly linked with analyses of spin and $\mathcal{CP}$ properties

- Needs to be practicable so that it can be implemented into the tools that are used so far for the “best” SM predictions

Effective Lagrangian from integrating out heavy particles

Assumption: new physics appears only at a scale $\Lambda \gg M_\mathrm{h} \sim 126~\mathrm{GeV}$

Systematic approach: expansion in inverse powers of Λ

$$\Delta\mathcal{L} = \sum_i \frac{a_i}{\Lambda^2}\mathcal{O}_i^{d=6} + \sum_j \frac{a_j}{\Lambda^4}\mathcal{O}_j^{d=8} + \ldots$$

$\Rightarrow$ Higher-dimensional operators, parametrise effects of tree-level exchange and loop contributions of new heavy degrees of freedom

$\Rightarrow$ can parametrise deviations from the SM in terms of coefficients a_i (for on-shell matrix elemements some operators can be eliminated via eqns of motion)

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$\Rightarrow$ Analyses in terms of SM $+$ effective Lagrangian and in specific BSM models: MSSM, . . . are complementary

Which higher-dimensional operators should be considered?

- Buchmüller, Wyler (BW) basis: [*W. Buchmüller, D. Wyler '86*]

  Leads to 29 free coupling parameters from operators that are relevant for Higgs physics ($\mathcal{CP}$-conserving and $\mathcal{CP}$-violating)

  Constraints from eqns of motion, FCNC, ...

- Proposal by R. Contino et al.: [*R. Contino et al. '12*]

  Non-linear realisation of electroweak symmetry in unitary gauge, does not assume that new state is part of an $SU(2)_L$ doublet

  Constraints from SU(2) custodial symmetry, FCNC

  For small deviations from the SM: relations between coefficients, lead to BW-type parametrisation

  Current version assumes: new state is $\mathcal{CP}$-even scalar

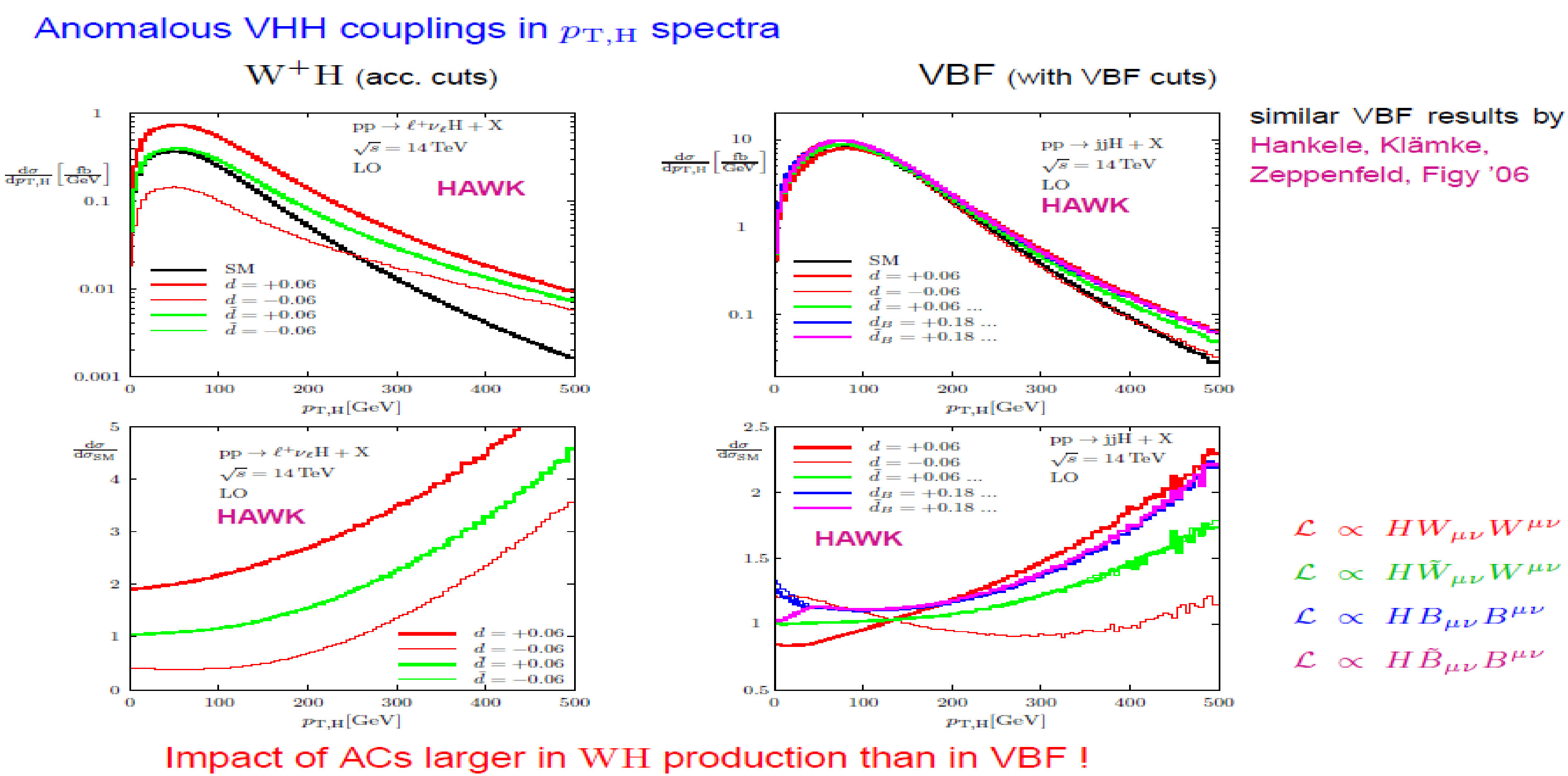
Some open issues

- Work with one or two parametrisations?
- Should higher-dimensional operators be inserted in loops?
  Classification of "admissible operators", see [*G. Passarino '12*]
- Parametrise loop effects by free parameters?
- Impact of bad high-energy behaviour of anomalous couplings at high p_{T}?
- Treatment of light BSM states?
- ...

Implementation of parametrisations of deviations from the SM in tools for Higgs phenomenology

Ongoing efforts for *HAWK*, *VBFNLO*, *Prophecy4f*, *HDECAY*, . . .

Example: Impact of anomalous VHH couplings on Higgs p_{T} spectra in WH and WBF [*S. Dittmaier '12*]



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- "Interim recommendations" for testing deviations of couplings from the SM:
  Various assumptions, scaling of couplings
  Interpretation of the results in BSM models?
- Coupling analyses beyond 2012: "best" SM predictions $+$ effective Lagrangian parametrisation; work in progress
- Complementarity: analysis in terms of SM $+$ effective Lagrangian and in specific BSM models: MSSM, ...
- Higgs searches are not over:
  The best way of experimentally proving that the observed state is not the SM Higgs is to find in addition (at least one) non-SM like Higgs!