Higgs Couplings at the LHC: Theory Aspects

Sven Heinemeyer, IFCA (CSIC–UC)

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1. Motivation

2. SM analysis

3. Beyond the SM

4. Conclusions

1. Motivation

Discovering the Higgs boson: what has to be done?

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Discovering the Higgs boson: what has to be done?

1. Find the new particle — T
2. measure its mass ($\Rightarrow$ ok?) — T
3. measure coupling to gauge bosons
4. measure couplings to fermions
5. measure self-couplings
6. measure spin, . . .

T = Tevatron,

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Discovering the Higgs boson: what has to be done?

1. Find the new particle	T	L
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4. measure couplings to fermions		L
5. measure self-couplings		
6. measure spin, . . .		

T = Tevatron, L = LHC,

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Discovering the Higgs boson: what has to be done?

1. Find the new particle	T	L	I
2. measure its mass ($\Rightarrow$ ok?)	T	L	I
3. measure coupling to gauge bosons		L	I
4. measure couplings to fermions		L	I
5. measure self-couplings			I
6. measure spin, ...			I

T = Tevatron, L = LHC, I = ILC (International Linear e^+e^- collider)

We need the LHC and the ILC to find the Higgs
and to establish the Higgs mechanism!

The LHC can do a crucial part ...

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Discovering the Higgs boson: what has to be done?

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What is a coupling?

$\longrightarrow$ parameter in the tree-level Lagrangian

$$\mathcal{L} = \ldots g_{HZZ} HZZ + \ldots g_{Hb\bar{b}} Hb\bar{b} + \ldots$$

$\Rightarrow$ these parameters show the symmetries expected from the Higgs mechanism, i.e.

coupling $\propto$ mass

$\Rightarrow$ factor out radiative corrections (depending on the model . . .)

2. SM analysis

[*M. Dührssen et al. '04*]

Measurements for a SM Higgs (or SM-like MSSM Higgs) at the LHC:

Measurement of $\sigma \times$ BR: "narrow width" approximation:

$$\Rightarrow \sigma(H) \times \text{BR}(H \to xx) = \sigma(H)^{\text{SM}} \cdot \frac{\Gamma_{\text{prod}}}{\Gamma_{\text{prod}}^{\text{SM}}} \times \frac{\Gamma_{\text{partial}}}{\Gamma_{\text{tot}}}$$

Observation of different channels

$\Rightarrow$ Information about combinations of $\Gamma_b, \Gamma_\tau, \Gamma_W, \Gamma_Z, \Gamma_g, \Gamma_\gamma, Y_t^2$

$\Rightarrow$ Additional theory assumptions necessary for absolute determination of partial widths

Only assumption:

$$g_{HVV}^2 \leq g_{HVV}^{2\,\text{SM}} \times 1.05$$

$\to$ fulfilled in general multi Higgs-Doublet model
w/o additional Higgs-Singlets (⇒ includes e.g. MSSM)

$\Rightarrow$ Absolute Determination of Γ_{tot} and Higgs couplings in a global fit

Estimate of errors:

1.) Statistical errors:

Assumption: SM rates for production and decay in all scenarios

2.) Systematic errors:

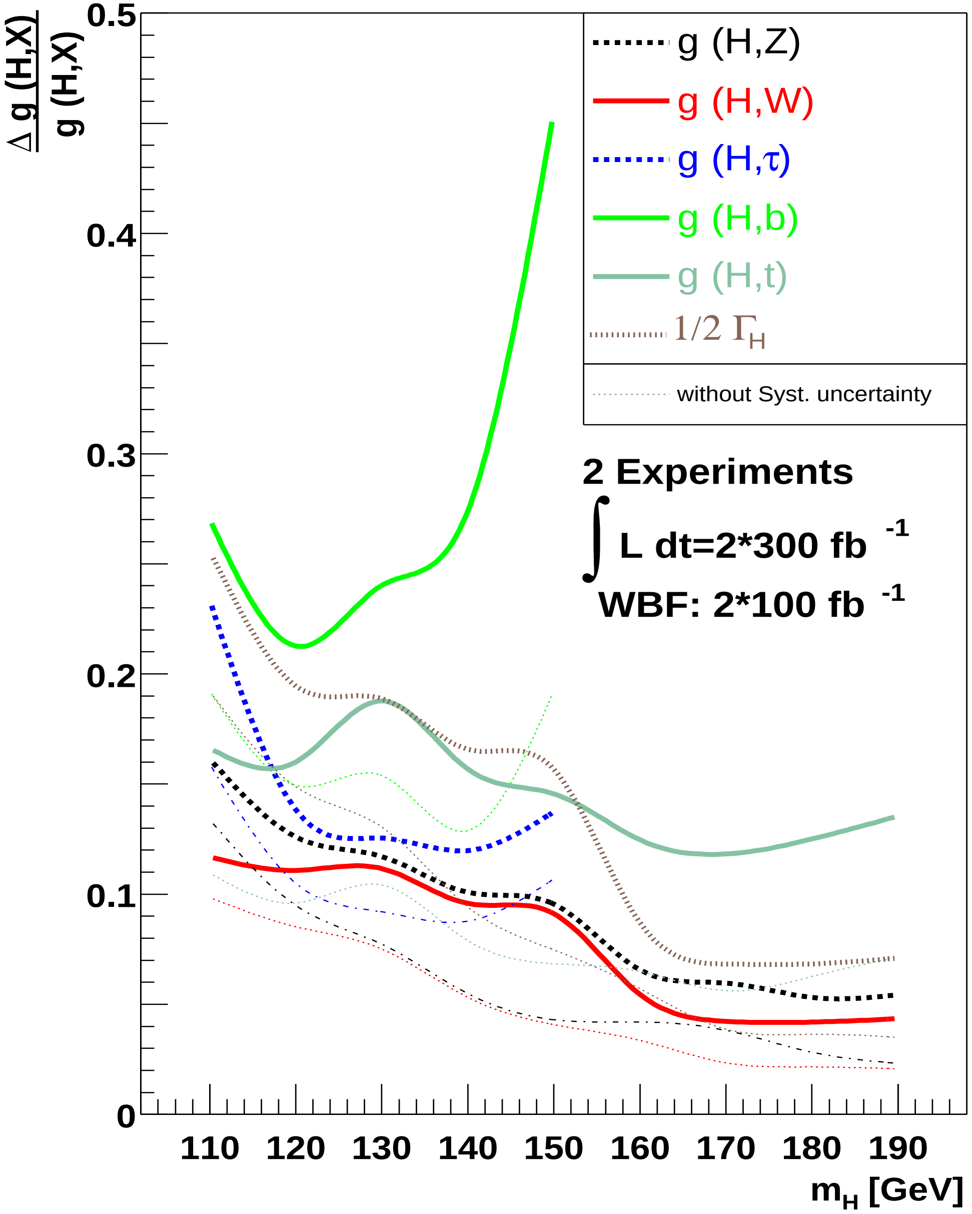
$\rightarrow$ attempt to include realisticly all possible errors

QCD and PDF uncertainties:

channel	uncertainty
GF	20%
$t\bar{t}H$	15%
WH	7%
ZH	7%
WBF	4%

$\Rightarrow$ "log likelihood" function,
based on statistical and systematic errors

Relative precision for partial and total Higgs widths: two scenarios



With mild theory assumptions:

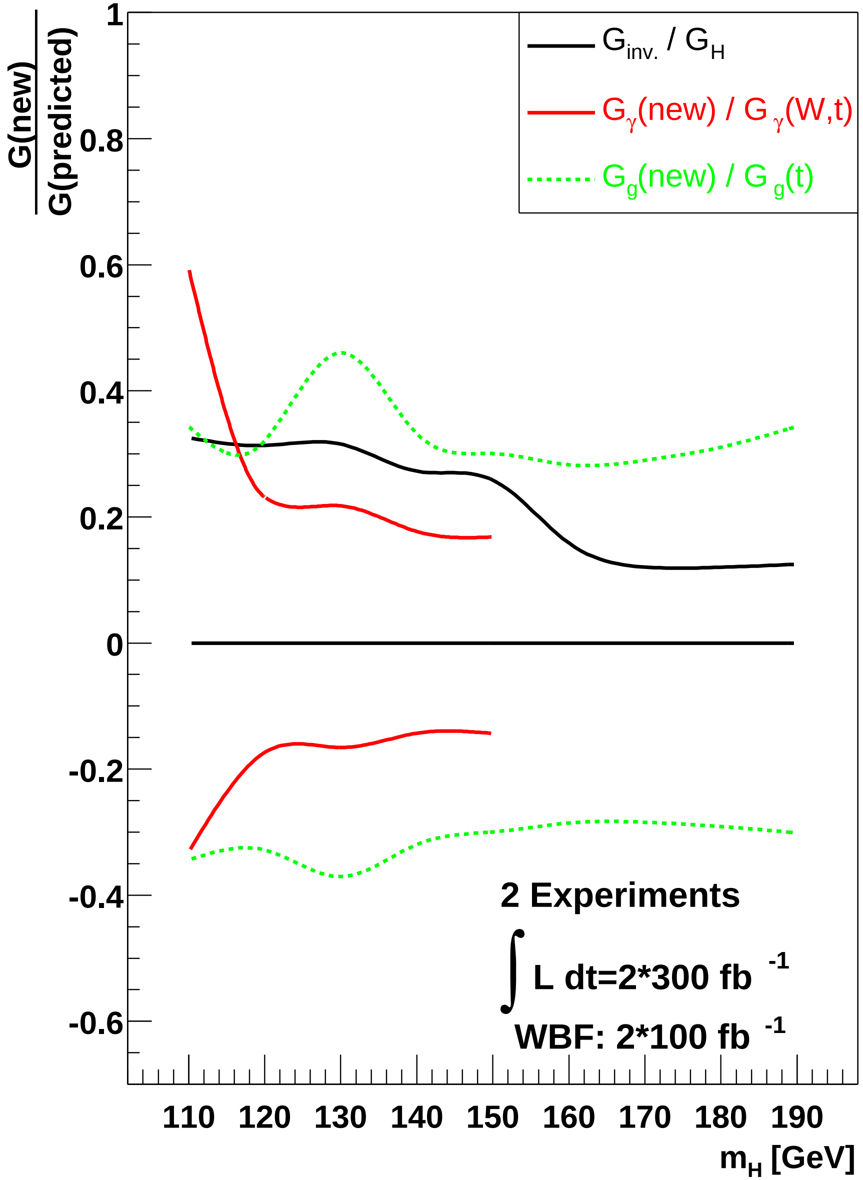
– typical accuracies of 10-15% for $m_H \leq 150$ GeV

– 5% accuracies for HVV couplings above WW threshold

⇒ Is this precision sufficient (for us)?

⇒ Discrimination of models?

Constraints on extra partial widths:



measurement of SM rates

⇒ constraints on widths:

$$\Delta\Gamma_\gamma \leq 0.2 \times \Gamma_\gamma^{SM}$$

$$\Delta\Gamma_g \leq 0.4 \times \Gamma_g^{SM}$$

$$\Delta\Gamma_{inv} \leq 0.2 \times \Gamma_{tot}^{SM}$$

⇒ Is this precision sufficient (for us)?

⇒ Discrimination of models?

Theory aspects: how could the accuracy be increased?

- narrow width approximation:

  Sufficient? Error estimate?
  What can be gained with a full n-loop calculation?

- $g^2_{HVV} \le g^{2\,\text{SM}}_{HVV} \times 1.05$:

  $\to$ for theoretical uncertainties in the translation between couplings-squared and partial widths
  Reduction possible?

- error assumptions:

channel	uncertainty
GF	20%
$t\bar{t}H$	15%
WH	7%
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  Reduction possible?
  Intrinsic uncertainties? Parametric uncertainties?

$\Rightarrow$ Assessment of overall possible improvement?

Q: Is it possible to overcome the model assumptions?

3. Beyond the SM

Main ideas:

A) Test the Higgs mechanism, possible in BSM?

B) Discriminate between various models via the Higgs sector?

C) Indirect determination of unknown Higgs sector parameters?

D) . . .

3. A) Test the Higgs mechanism, possible in BSM?

What happens to SM analysis if . . .

- Some couplings change substantially?
  - $t\bar{t}H$ with $H \to b\bar{b}$ is suppressed?
  - $H \to b\bar{b}$ is strongly enhanced?
  - WBF is suppressed?
  - $gg \to H$ is suppressed?

- M_H cannot be measured with $\delta M_H \approx 200$ MeV?

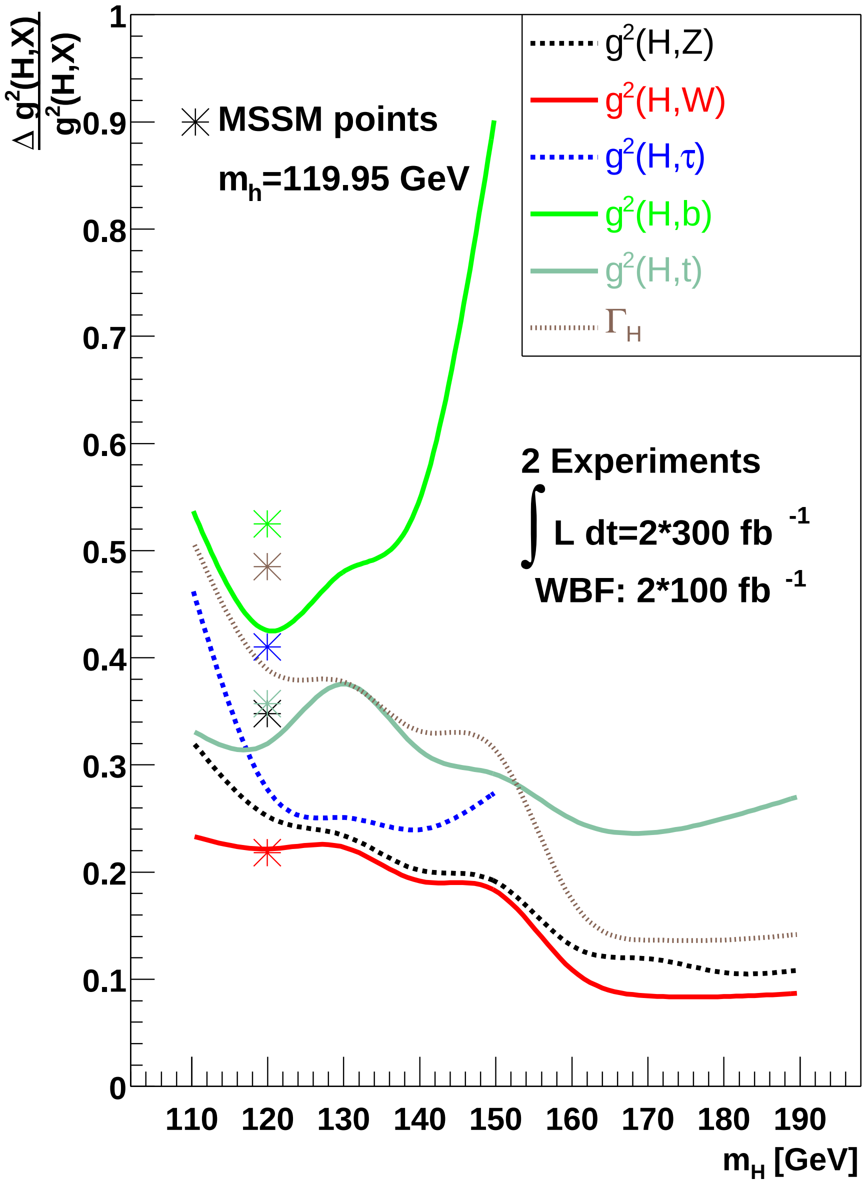
  other channels?

  multi-channel fit?

- several Higgs bosons are observed?

$\Rightarrow$ Mostly not analyzed yet!

One MSSM example: [*M. Dührssen et al. '04*]



scenario with large $\tan\beta$:

$h \to b\bar{b}$ enhanced

$h \to \tau^+\tau^-$ enhanced

BR($h \to VV^*$) $\approx$ 1/2 SM

BR($h \to \gamma\gamma$) $\approx$ 1/2 SM

BR($h \to gg$) $\approx$ 1/5 SM

$\Rightarrow$ not too bad . . .

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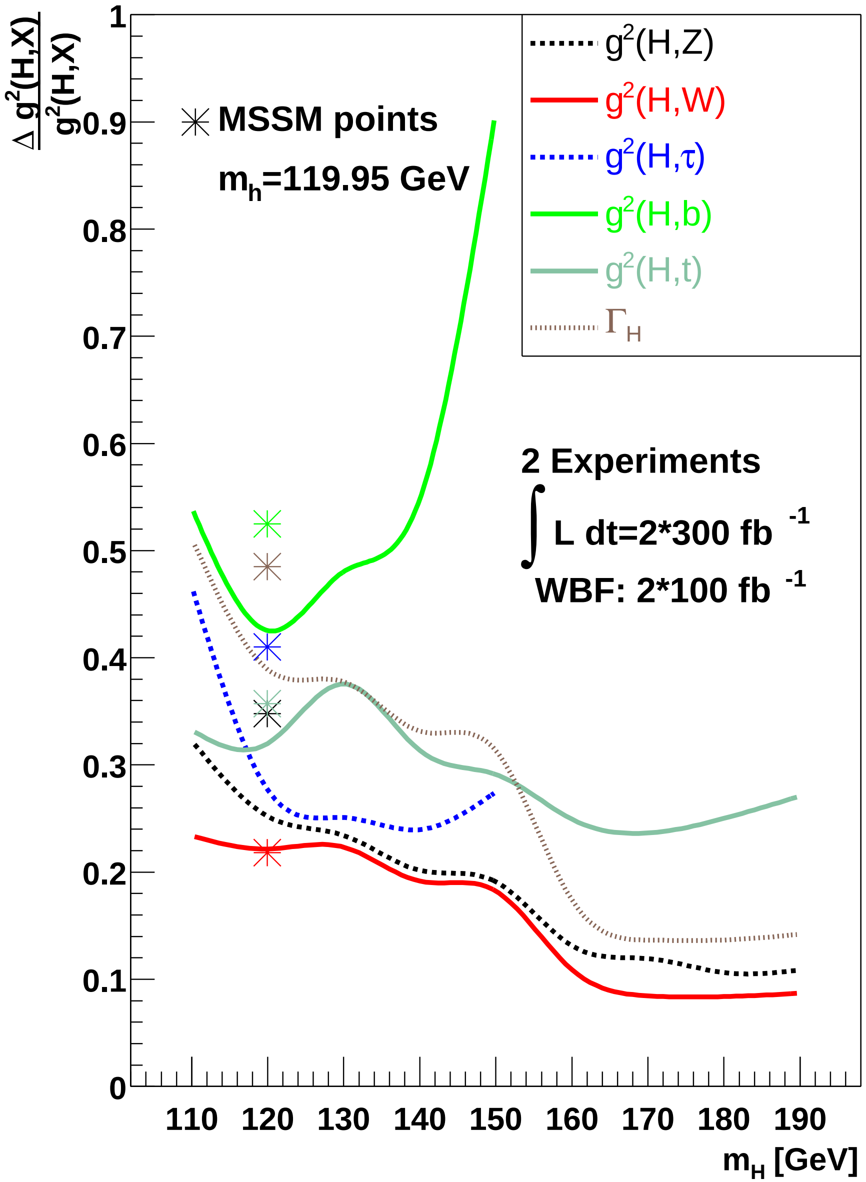

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BR($h \to gg$) $\approx$ 1/5 SM

$\Rightarrow$ not too bad . . .

$\Rightarrow$ more analyses needed!

⇒ more analyses needed!   ⇒ new problems arise:

– Needed: calculations in BSM of

  – Higgs production cross sections
  – Higgs BR's
    (or better full processes?)

– These calculations have new uncertainties that have to be included in any realistic analysis:

  – new intrinsic uncertainties
  – new parametric uncertainties

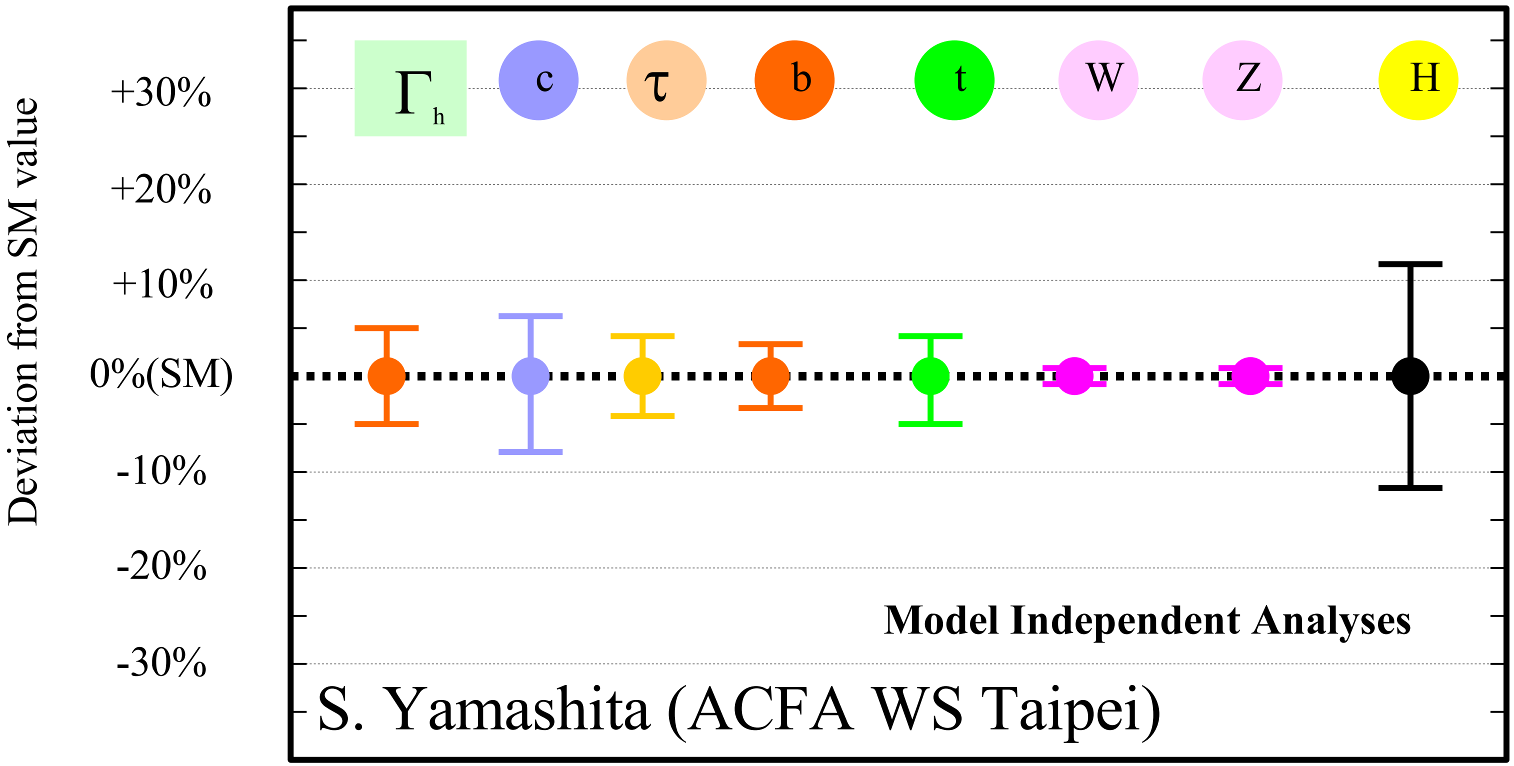
⇒ evaluate $\mathcal{O}^{\rm BSM}$ and $\Delta^{\rm theo}\mathcal{O}^{\rm BSM}$

– New calculations have to be used for experimental analyses
  ⇒ joint effort of theory and experiment

3. B) Discriminate between various models via the Higgs sector

Some ILC "propaganda" plots (I):

Precision for coupling measurements: SM

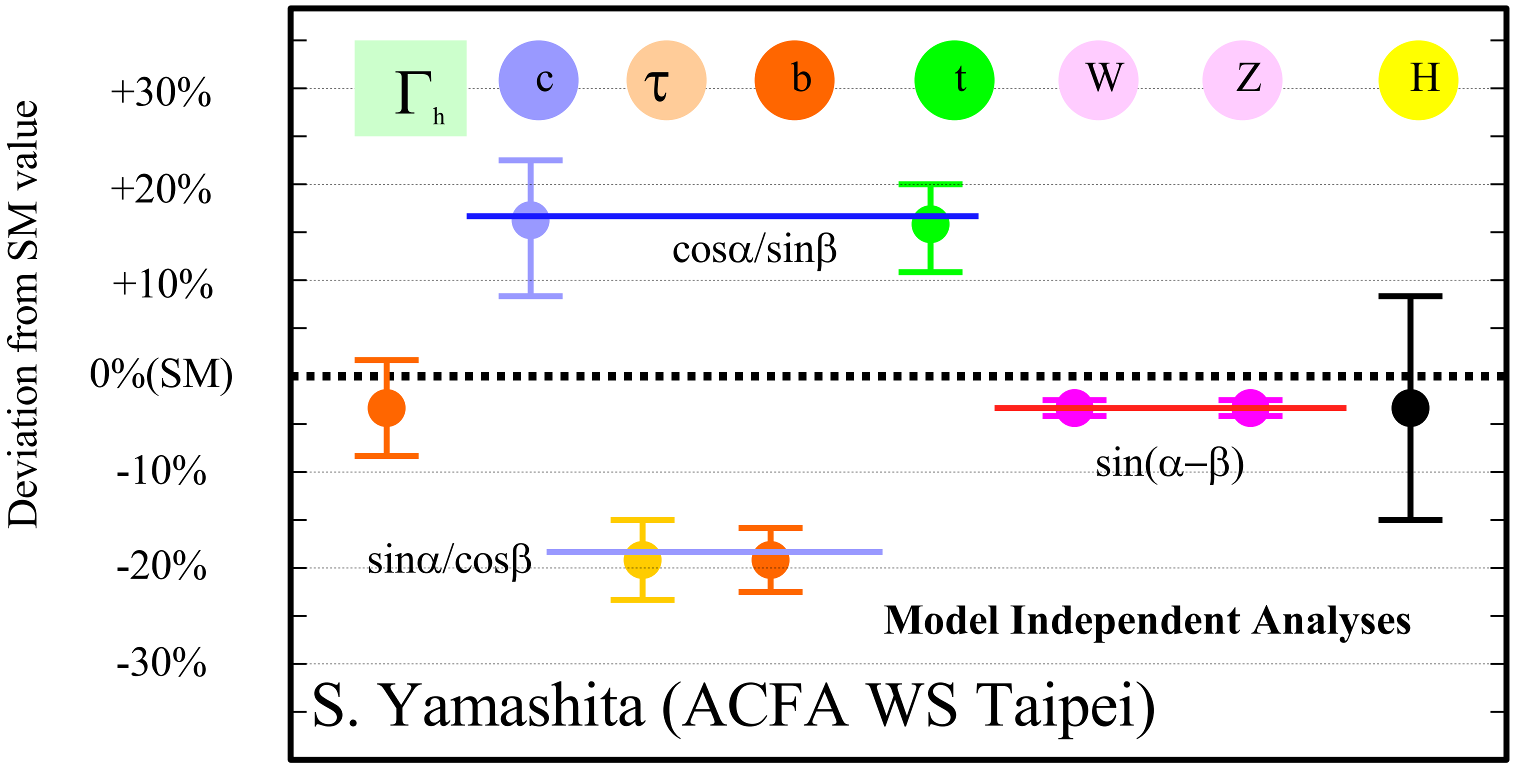


$\Delta g^{\text{LHC}}_{Hf\bar{f}}/g_{Hf\bar{f}} \gtrsim 15\%$, $\Delta g^{\text{LHC}}_{HVV}/g_{HVV} \gtrsim 5\%$

3. B) Discriminate between various models via the Higgs sector

Some ILC "propaganda" plots (II):

Precision for coupling measurements: "easy" MSSM example

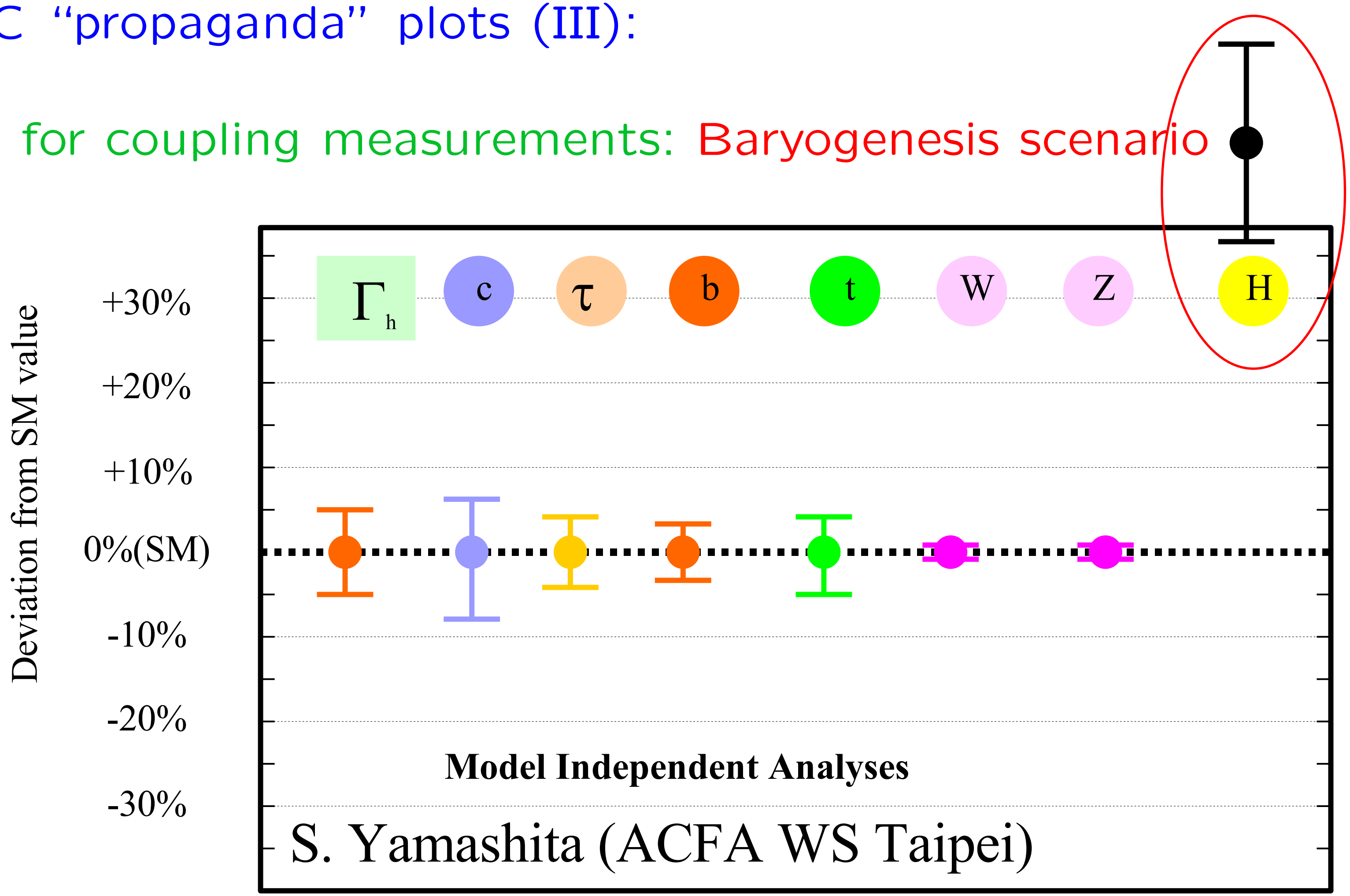


$\Delta g^{\text{LHC}}_{Hf\bar{f}}/g_{Hf\bar{f}} \gtrsim 15\%$, $\Delta g^{\text{LHC}}_{HVV}/g_{HVV} \gtrsim 5\%$

3. B) Discriminate between various models via the Higgs sector

Some ILC "propaganda" plots (III):

Precision for coupling measurements: Baryogenesis scenario



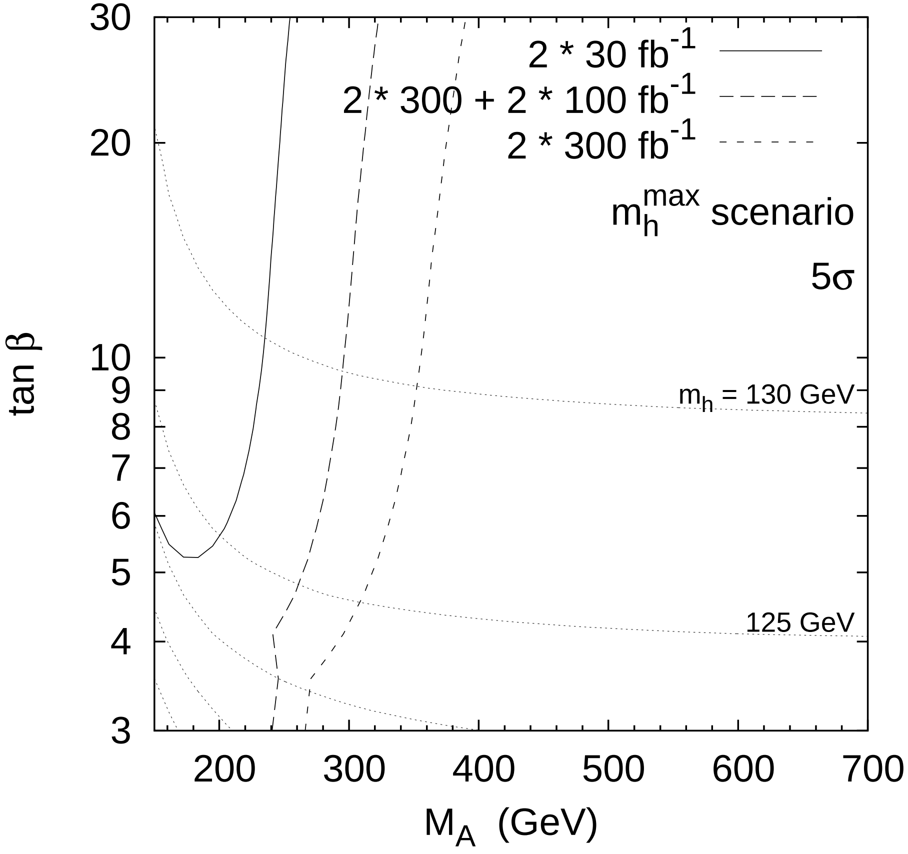
$\Delta g^{\text{LHC}}_{Hf\bar{f}}/g_{Hf\bar{f}} \gtrsim 15\%$, $\Delta g^{\text{LHC}}_{HVV}/g_{HVV} \gtrsim 5\%$

Needed: analysis of LHC reach in BSM

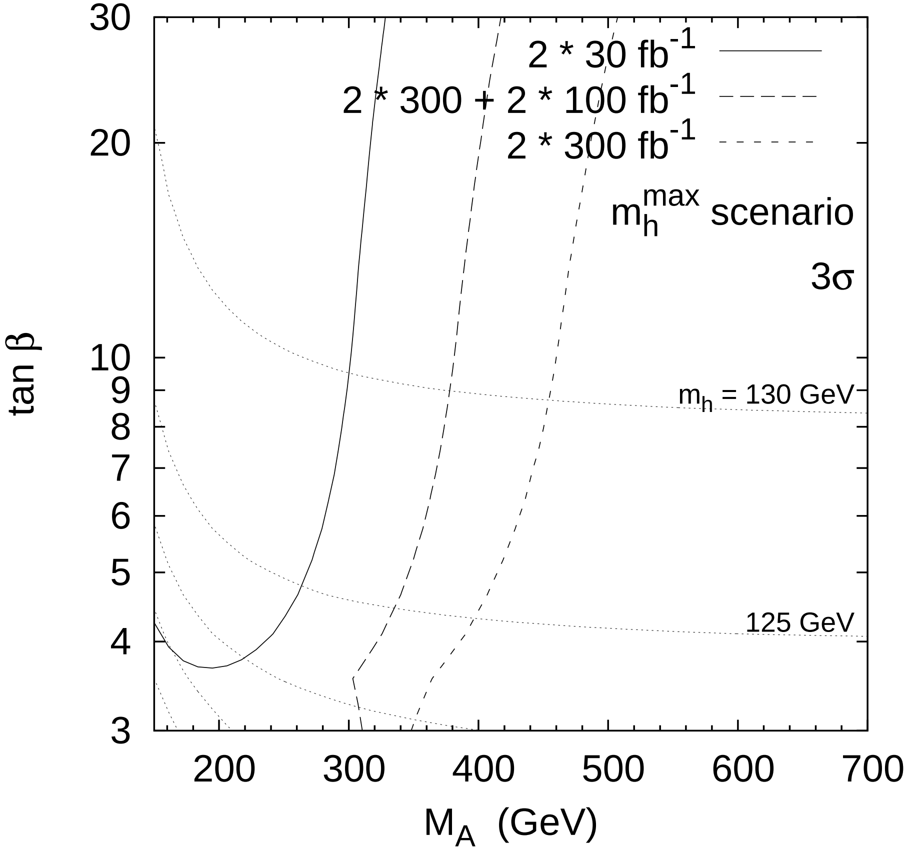
Example: MSSM *[H. Logan et al. '04]*

Global fit to all channels: where is the MSSM different from SM?

5 σ, $m_h^{\rm max}$

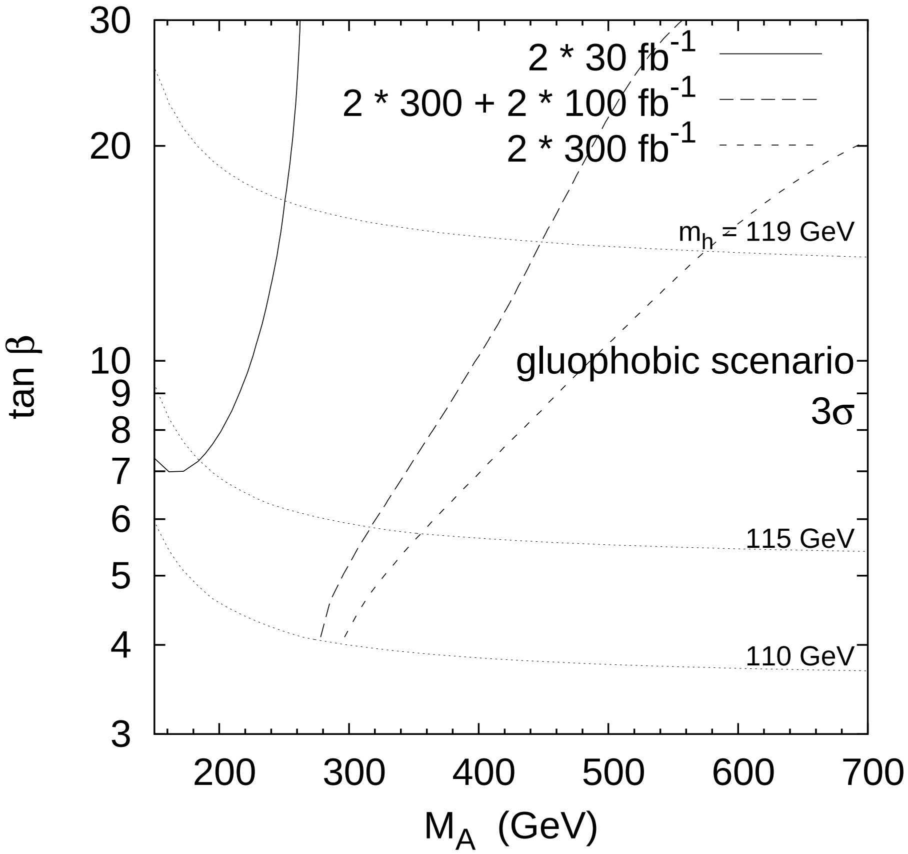


3 σ, $m_h^{\rm max}$

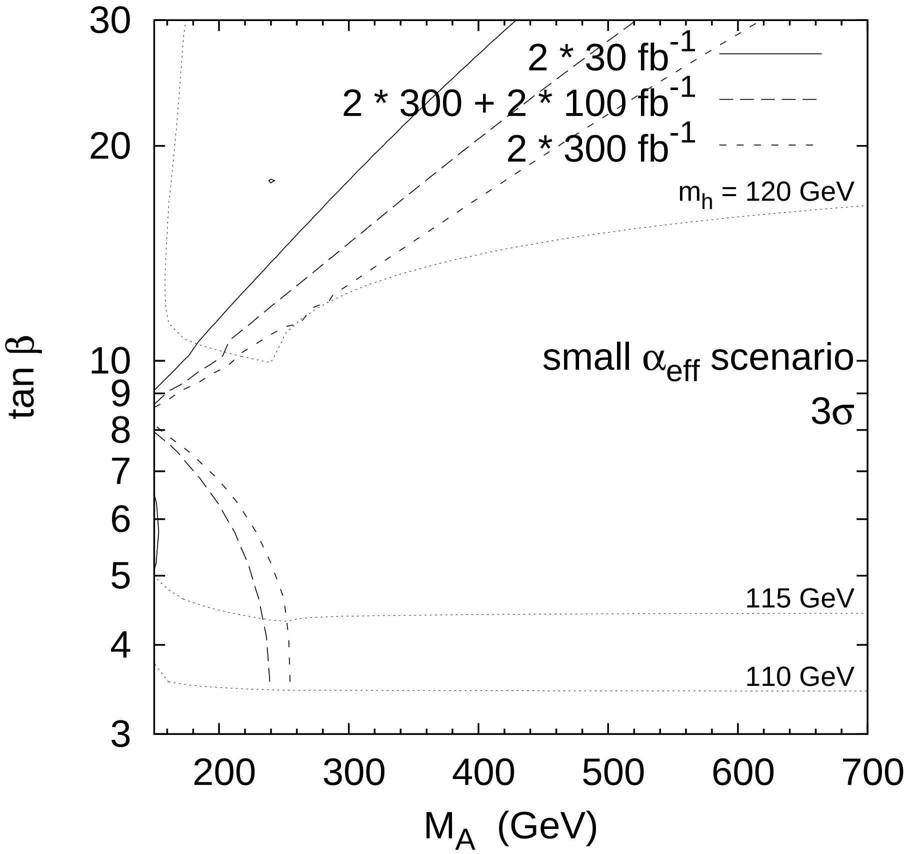


Example: MSSM (other scenario) [*H. Logan et al. '04*]

3 σ, gluophobic Higgs



3 σ, small α_{eff}



$\Rightarrow$ drastically different from m_h^{max} scenario

$\Rightarrow$ many detailed analyses needed

⇒ many analyses needed!   ⇒ new problems arise:

– Needed: calculations in BSM of

  – Higgs production cross sections
  – Higgs BR's

    (or better full processes?)

– These calculations have new uncertainties that have to be included in any realistic analysis:

  – new intrinsic uncertainties
  – new parametric uncertainties

⇒ evaluate $\mathcal{O}^{\mathrm{BSM}}$ and $\Delta^{\mathrm{theo}}\mathcal{O}^{\mathrm{BSM}}$

– New calculations have to be used for experimental analyses
  ⇒ joint effort of theory and experiment

3. C) Indirect determination of unknown Higgs sector parameters

Example: MSSM: indirect determination of M_A in LHC wedge

Existing LHC analyses neglect:

– MSSM intrinsic uncertainties

– parametric SM uncertainties

– anticipated parametric MSSM uncertainties

⇒ existing analyses unrealistic

One analysis includes all uncertainties: [*K. Desch et al. '04*]

⇒ needs ILC uncertainty of $g_{hb\bar{b}}/g_{hWW^*}$

+ input for masses, mixing angles from LHC $\oplus$ ILC

⇒ any chance for LHC alone?

4. Conclusions

- Higgs couplings measurements are crucial for
  - verifying/falsifying the Higgs mechanism
  - discriminate models
  - indirect parameter determinations

- Improvement of SM analysis requires theory input:
  - reduce intrinsic uncertainties
  - “full” calculations?

- BSM analyses require theory input:
  - reduce intrinsic uncertainties
  - “full” calculations?
  - model dedicated analyses

  ⇒ Can we/do we want to wait till we know, which model is “required”?

⇒ Often joint effort of theory and experiment required!