Extracting Higgs boson couplings from LHC data

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Introduction: Higgs at the LHC

LHC has the capability to observe the Higgs boson in a variety of channels, especially in the intermediate mass range
114 GeV $< M_H \lesssim$ 200 GeV.
$\longrightarrow$ Test Higgs couplings to SM particles.

Higgs couplings determine the production cross sections and decay BRs.

By measuring rates in multiple channels, various combinations of couplings can be determined.

Some decays cannot be directly observed due to backgrounds, e.g., $H \to gg$, $H \to$ light quarks; no missing-mass spectrum measurement like at LC.

$\longrightarrow$ Absolute measurements of partial decay widths are only possible with additional theoretical assumptions.

Strategy

Earlier strategies:

- Assume no unexpected decay channels

  $\longrightarrow$ total width extraction from observed modes
- Assume SM ratio of H couplings to $b\bar{b}$ and $\tau\tau$ [Zeppenfeld, Kinnunen, Nikitenko, Richter-Was, 2000] – needed since no $b\bar{b}$ channel included in analysis (tough – QCD bg).

  $\longrightarrow$ Not necessarily true in MSSM!

Improved analysis [Belyaev & Reina, 2002] included $b\bar{b}$ channel to remove this assumption.

Our strategy:

Assume HWW and HZZ couplings are bounded from above by their SM values.

Mild assumption: true in general multi-Higgs-doublet models (with or without additional Higgs singlets) – MSSM!

Strategy, continued

Observation of Higgs production

$\longrightarrow$ lower bound on production couplings

$\longrightarrow$ lower bound on Higgs total width.

Theoretical constraint $\Gamma_V \leq \Gamma_V^{\rm SM}$

$\oplus$ measurement of $\Gamma_V^2/\Gamma_{\rm tot}$ from WBF $\to H \to VV$

$\longrightarrow$ upper bound on Higgs total width.

This interplay provides constraints on remaining Higgs couplings.

A second approach: fit the observed rates to a particular model.
We do χ^2 fits in specific MSSM scenarios.

Higgs boson channels

GF $gg \to H \to ZZ$

WBF $qqH \to qqZZ$

GF $gg \to H \to WW$

WBF $qqH \to qqWW$

WH, $H \to WW$

$t\bar{t}H$, $H \to WW$

Inclusive $H \to \gamma\gamma$

WBF $qqH \to qq\gamma\gamma$

$t\bar{t}H$, $H \to \gamma\gamma$

WH, $H \to \gamma\gamma$

ZH, $H \to \gamma\gamma$

WBF $qqH \to qq\tau\tau$

$t\bar{t}H$, $H \to b\bar{b}$

GF = gluon fusion
WBF = weak boson fusion

Systematic uncertainties

5% Luminosity normalization

Theory uncertainties on Higgs production:

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

Reconstruction/identification efficiencies:

- 2% leptons
- 2% photons
- 3% b quarks
- 3% τ jets
- 5% forward tagging jets and veto jets (WBF)

Background extrapolation from side-bands (shape):

- from 0.1% for $H \to \gamma\gamma$
- to 5% for $H \to WW$ and $H \to \tau\tau$
- to 10% for $H \to b\bar{b}$

Luminosity assumptions

Three LHC luminosity scenarios:

- Low lumi, 30 fb^{-1} $\times$ 2 detectors

- High lumi, 300 fb^{-1} $\times$ 2 detectors

- Mixed, 300 fb^{-1}, with only 100 fb^{-1} usable for WBF channels, $\times$ 2 detectors

The WBF channels have not yet been studied for high-luminosity LHC running.

The Mixed scenario will be important if underlying events from high-lumi running significantly degrade the efficiency of WBF channels.

General multi-Higgs-doublet model fits

• Assume $g^2_{W,Z} < 1.05 \ \left(g^2_{W,Z}\right)_{\mathrm{SM}}$

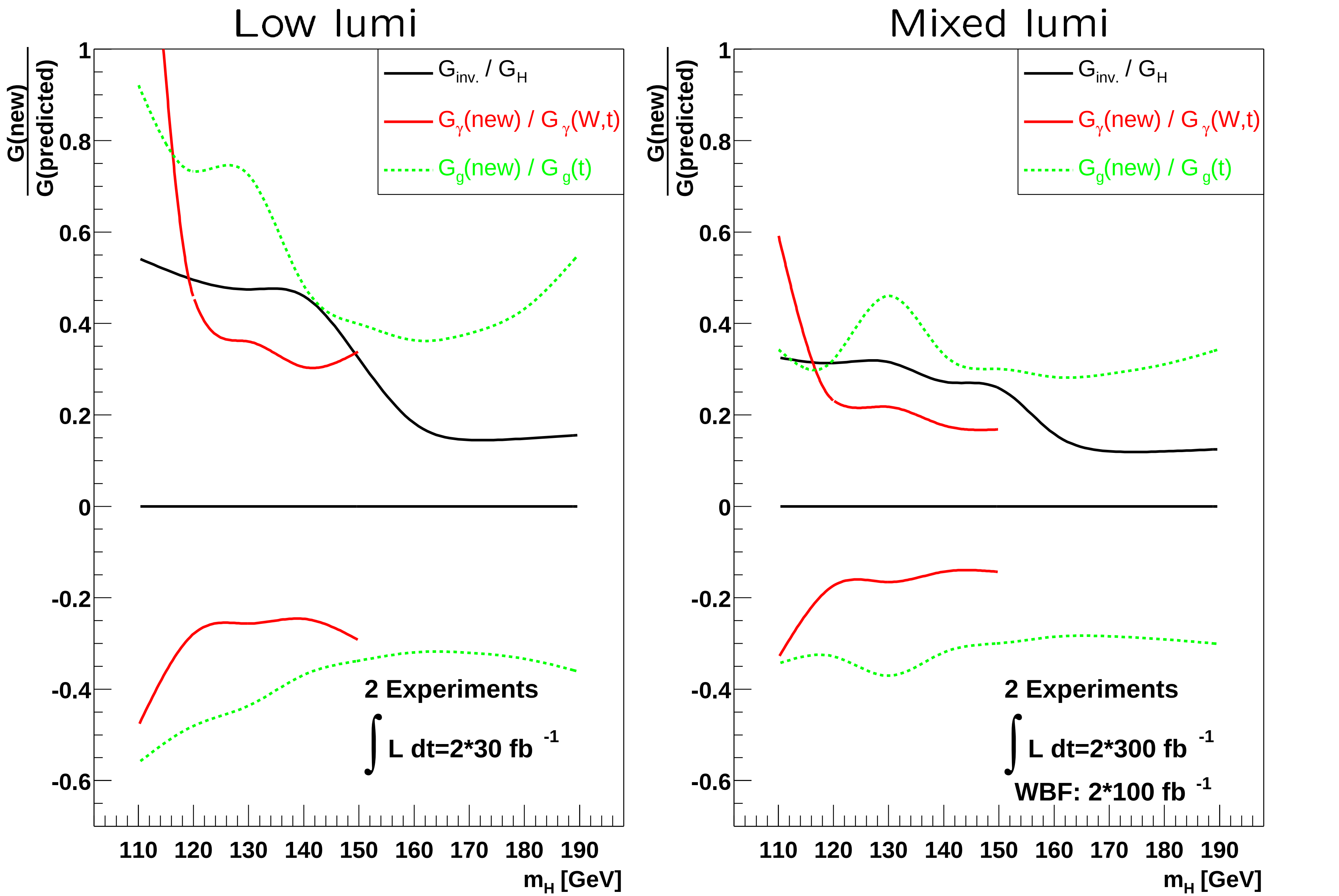
Extra 5% margin allows for theoretical uncertainties in the translation between couplings-squared and partial widths and also for small admixtures of exotic Higgs states, like SU(2) triplets.

• Allow for possibility of additional particles running in the loops for $H \to \gamma\gamma$ and $gg \to H$, fitted by a positive or negative new partial width to these contributions.

• Allow for additional light hadronic decays, fitted with a partial width for unobservable decays.

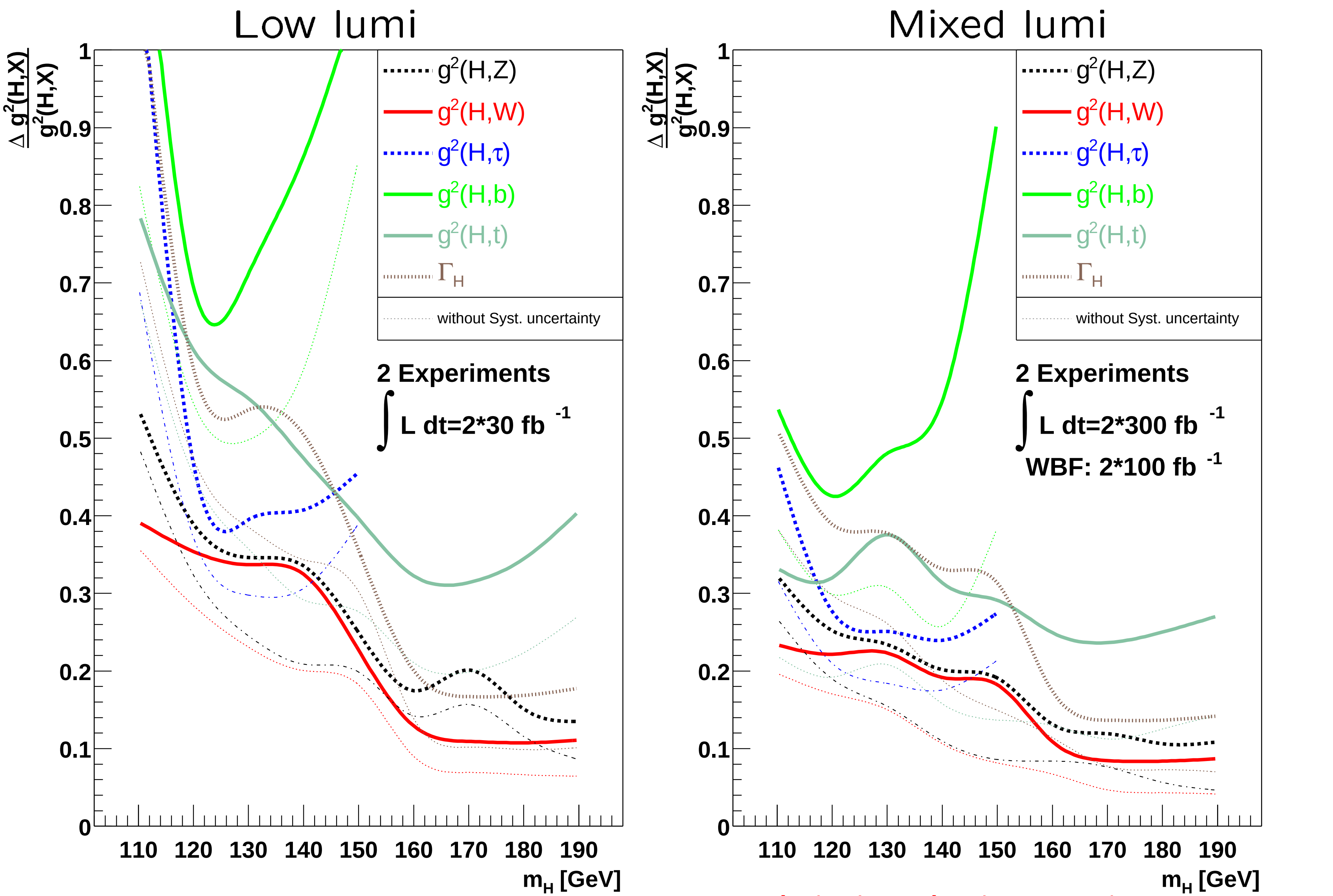
(Invisible decays, e.g. Higgs $\to$ neutralinos, could still be observable at the LHC in WBF [Eboli & Zeppenfeld, 2000].)

General multi-Higgs-doublet model fits: unobservable decays, new particles in gg, $\gamma\gamma$ loops



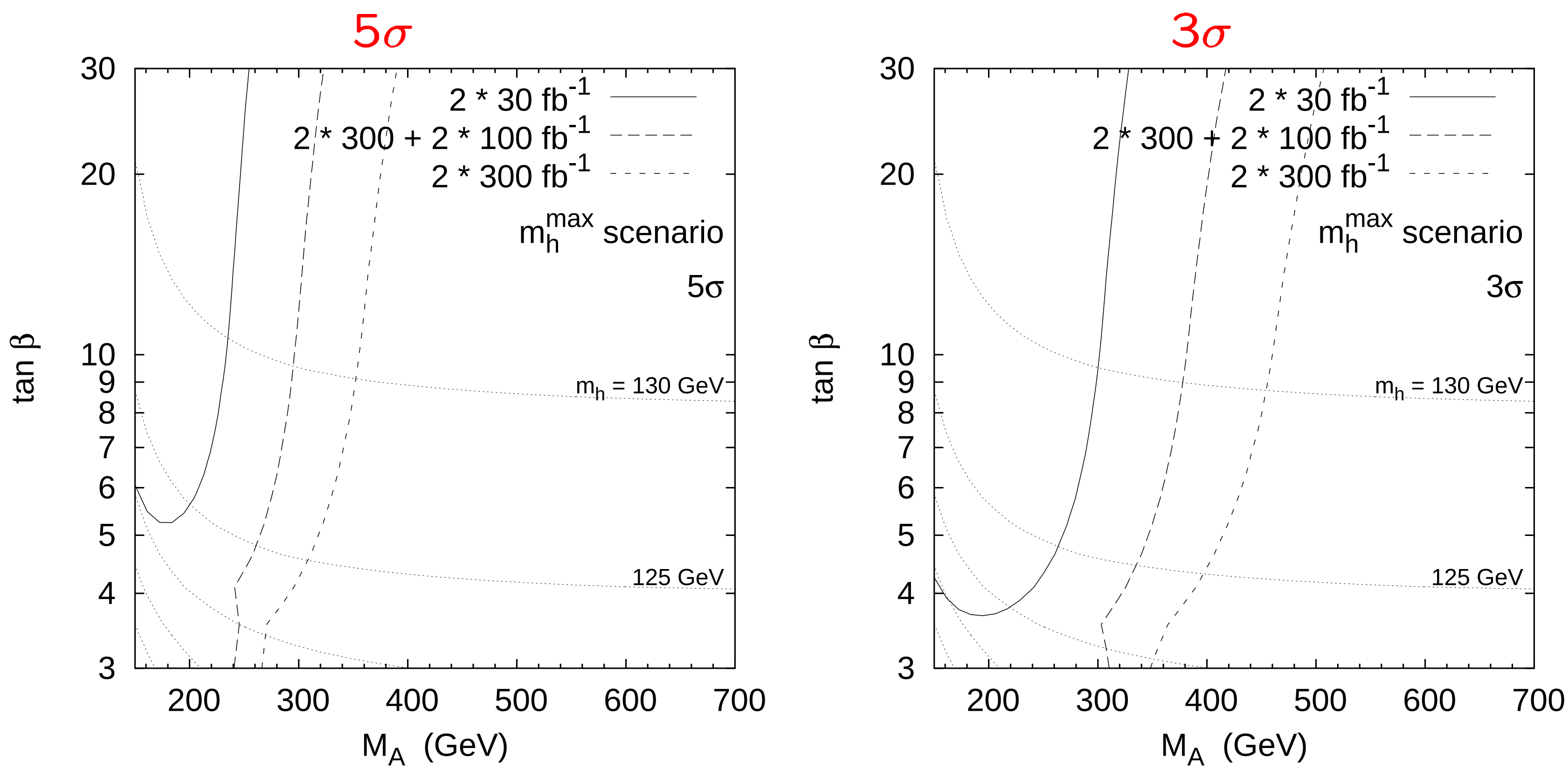
High lumi about the same.

General multi-Higgs-doublet model fits: couplings



High lumi about the same except τ improves.

Higgs couplings within the MSSM: m_h^{max} scenario

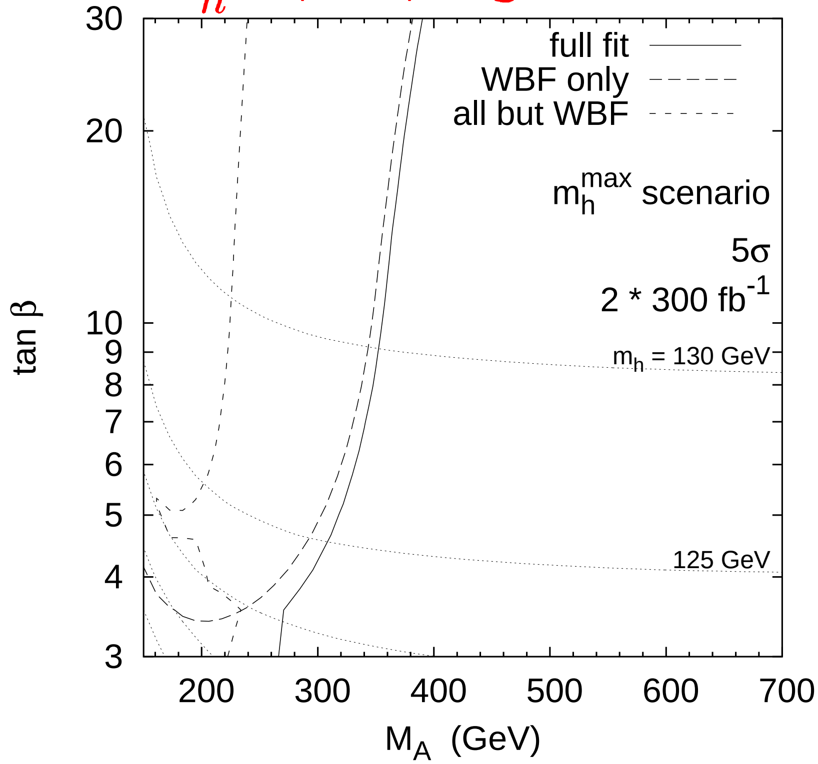


Sensitive to MSSM nature of h up to $M_A \lesssim 350$ GeV!
(m_h^{max}, 5σ, high lumi)

Higgs couplings within the MSSM: source of sensitivity

Sensitivity comes primarily from WBF channels.

m_h^{max}, 5σ, high lumi

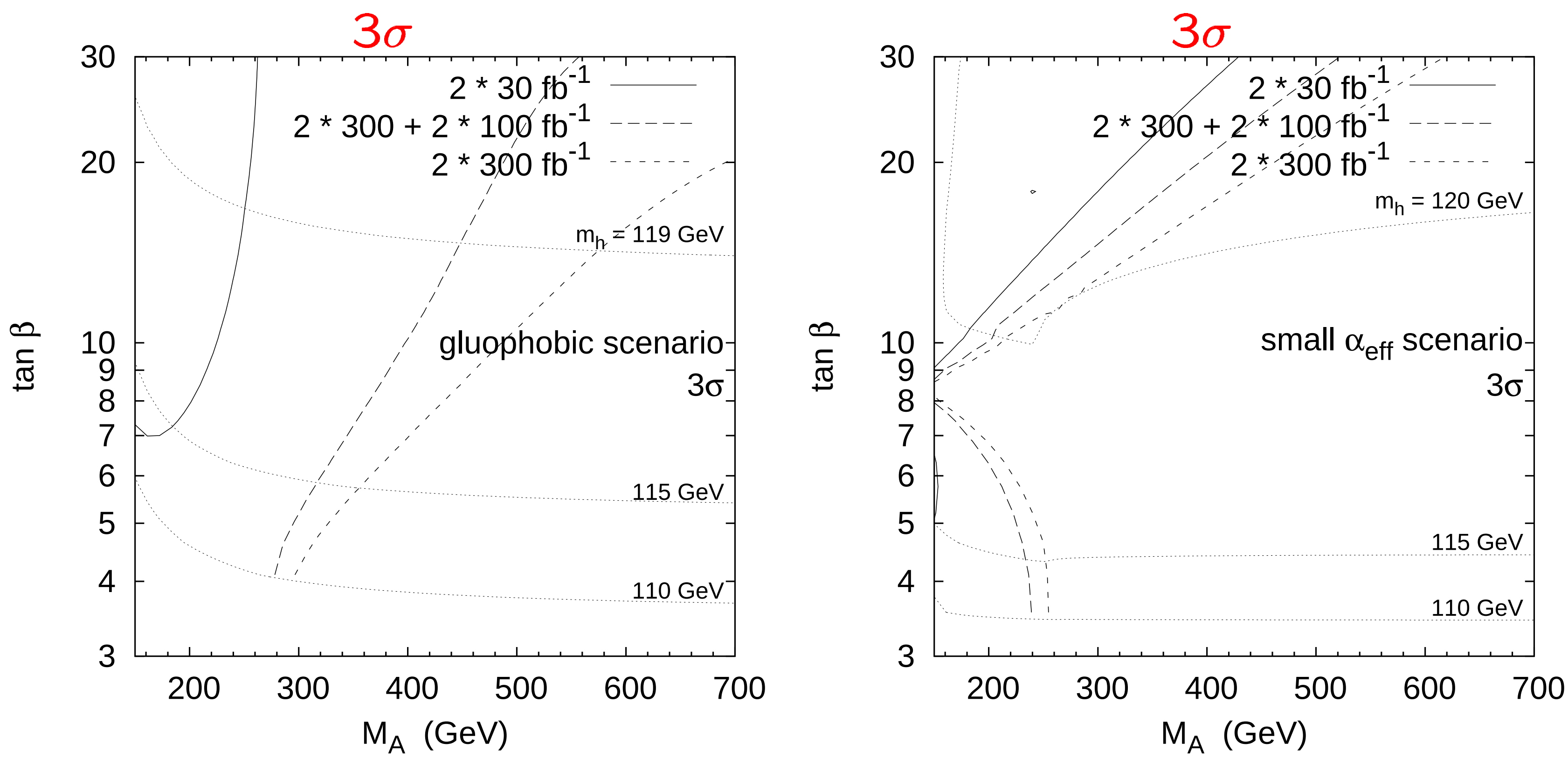


<u>MSSM Higgs couplings:</u>

- hWW, hZZ, hgg, $h\gamma\gamma$ decouple quickly
- $hb\bar{b}$, $h\tau\tau$ decouple slowly!
- BR($h \to WW$) decouples slowly – sensitive to $hb\bar{b}$ via Γ_{tot}.
- WBF $qqH \to qqWW$ sensitive to BR($h \to WW$)
- But systematics (lumi 5%, WBF thy 4%, tag/veto jets 5%) kill the sensitivity!
- Need to combine with WBF $qqH \to qq\tau\tau$ to normalize out the systematics.

Higgs couplings within the MSSM: other scenarios

Sensitivity depends strongly on MSSM parameters!
$\longrightarrow$ Need more information before one can use h coupling deviations as an indirect measurement of M_A.



Hadron collider benchmark scenarios [Carena, Heinemeyer, Wagner, Weiglein, 2003]

Conclusions

LHC Higgs production and decay data can be used to extract gauge and fermion couplings of Higgs bosons.

Theoretical assumptions needed to overcome correlations/ degeneracies caused by incomplete input data.

Very mild theoretical assumptions on HVV couplings lead to precisions in Higgs couplings between 10–40% for $M_H < 200$ GeV.

LHC is sensitive to MSSM nature of h out to $M_A \lesssim 350$ GeV in m_h^{max} scenario – mostly due to WBF channels. (5σ, high lumi)