Heavy Higgs couplings at the LHC

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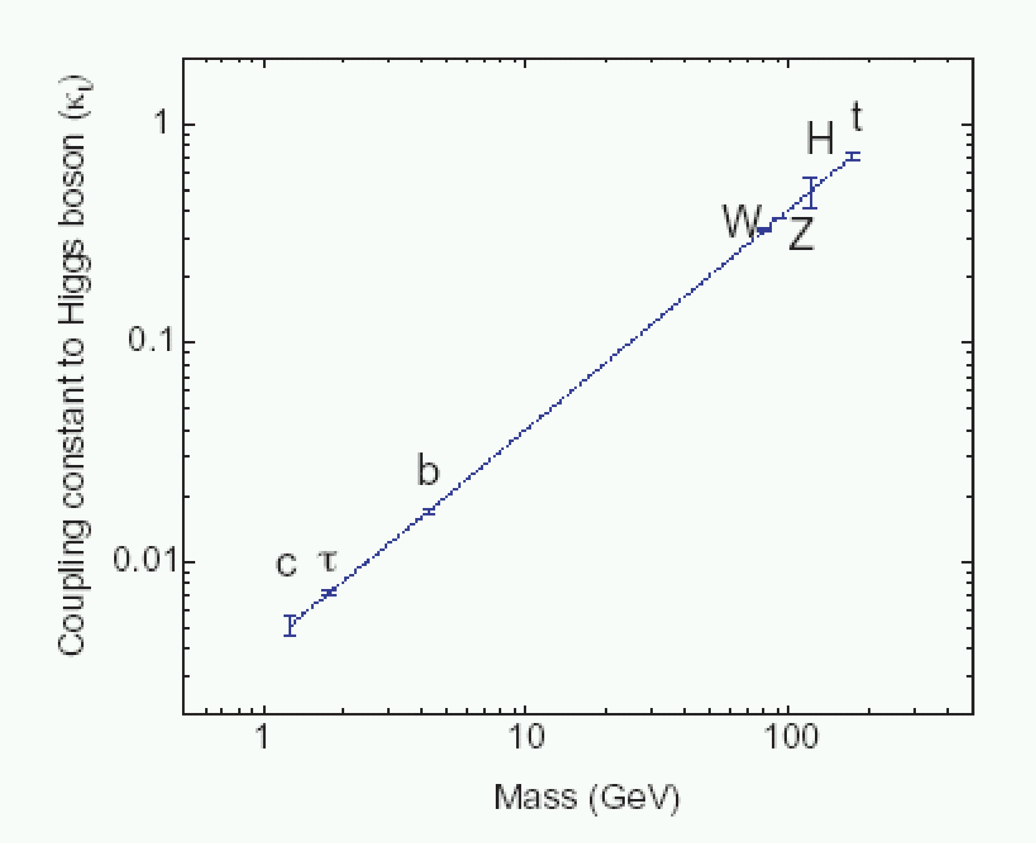
Based on H.E.L. and J.Z. Salvail, in preparation

Introduction

If a Higgs-like state is discovered, we'll need to answer the question, "Is it the (SM) Higgs?"

SM: coupling of Higgs to each SM particle already fixed by known particle masses.

BSM: couplings usually modified if Higgs sector is extended; pattern helps identify model.



To test the Standard Model Higgs mechanism, need to measure Higgs couplings.

Model-independent Higgs coupling measurements are one of the main selling points of ILC.

Coupling extraction more difficult at LHC due to absence of direct measurement of Higgs production cross section(s).

Measure event rates: sensitive to production and decay couplings

$$\text{Rate}_{ij} = \sigma_i \frac{\Gamma_j}{\Gamma_{\text{tot}}}$$

Allow an unobserved decay mode while simultaneously increasing all couplings by a factor a:

$$\text{Rate}_{ij} = a^2 \sigma_i^{\text{SM}} \frac{a^2 \Gamma_j^{\text{SM}}}{a^2 \Gamma_{\text{tot}}^{\text{SM}} + \Gamma_{\text{new}}}$$

"Flat direction" in the fit!

Previous studies dealt with this by imposing model assumptions: e.g., assume HWW, HZZ couplings no larger than in SM, or assume no unobserved decays.

Some history:

Get ratios of Higgs couplings-squared from taking ratios of rates. Full coupling extraction: assume no unexpected decay channels, assume $b\bar{b}/\tau\tau =$ SM value. $M_H =$ 100–190 GeV

Zeppenfeld, Kinnunen, Nikitenko, Richter-Was, PRD62, 013009 (2000); Les Houches 1999

Add $t\bar{t}H$, $H \to \tau\tau$ channel to improve $t\bar{t}H$ constraint.

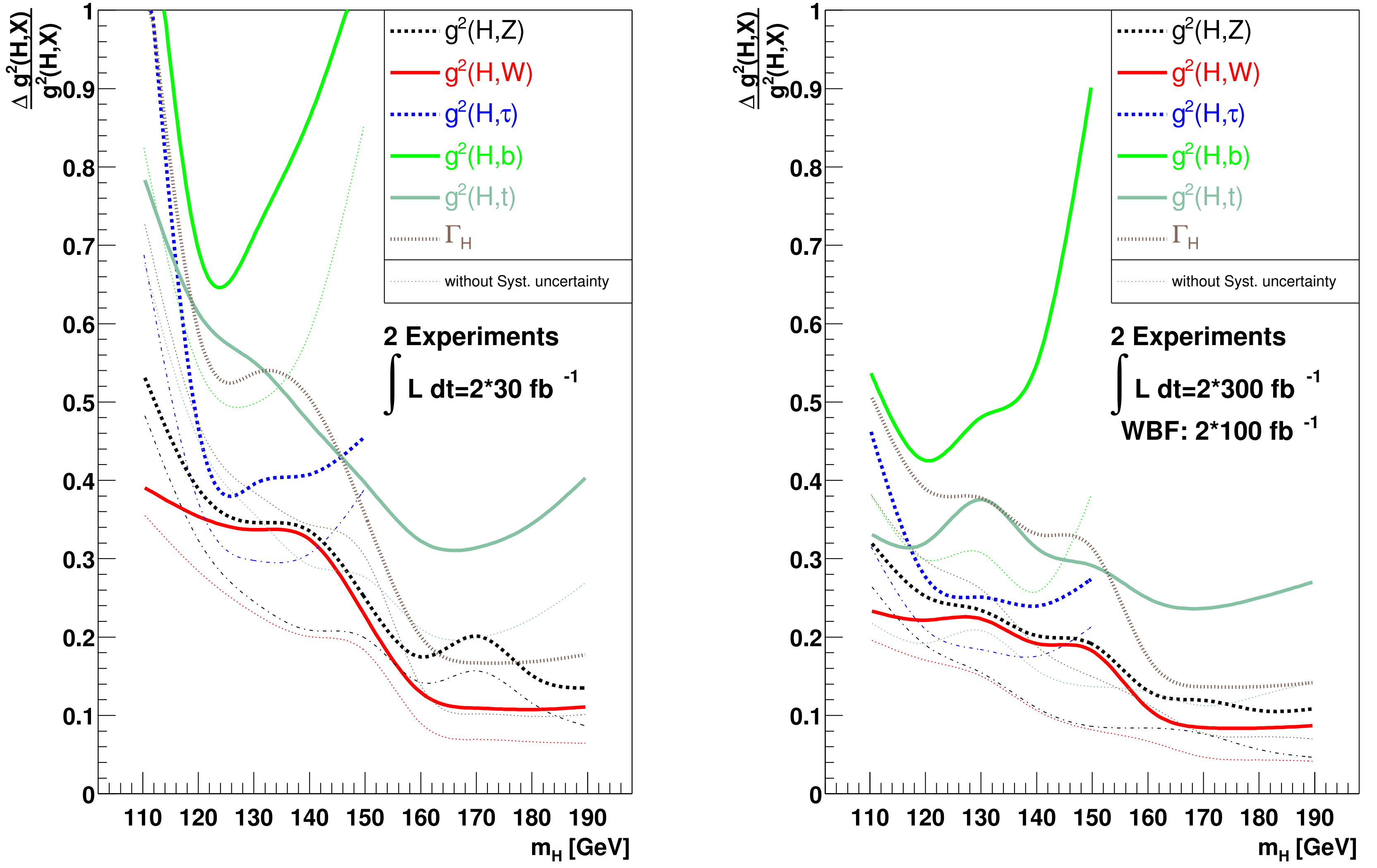
$M_H =$ 110–180 GeV Belyaev & Reina, JHEP0208, 041 (2002)

Fit assuming WWH, ZZH couplings bounded from above by SM value. $M_H =$ 110–190 GeV

Dührssen, Heinemeyer, HEL, Rainwater, Weiglein, & Zeppenfeld, PRD70, 113009 (2004)

More careful analysis of probability density and correlations, using updated expt studies. Assume no unexpected decay channels.

$M_H =$ 120 GeV Lafaye, Plehn, Rauch, Zerwas, & Dührssen, JHEP0908, 009 (2009)



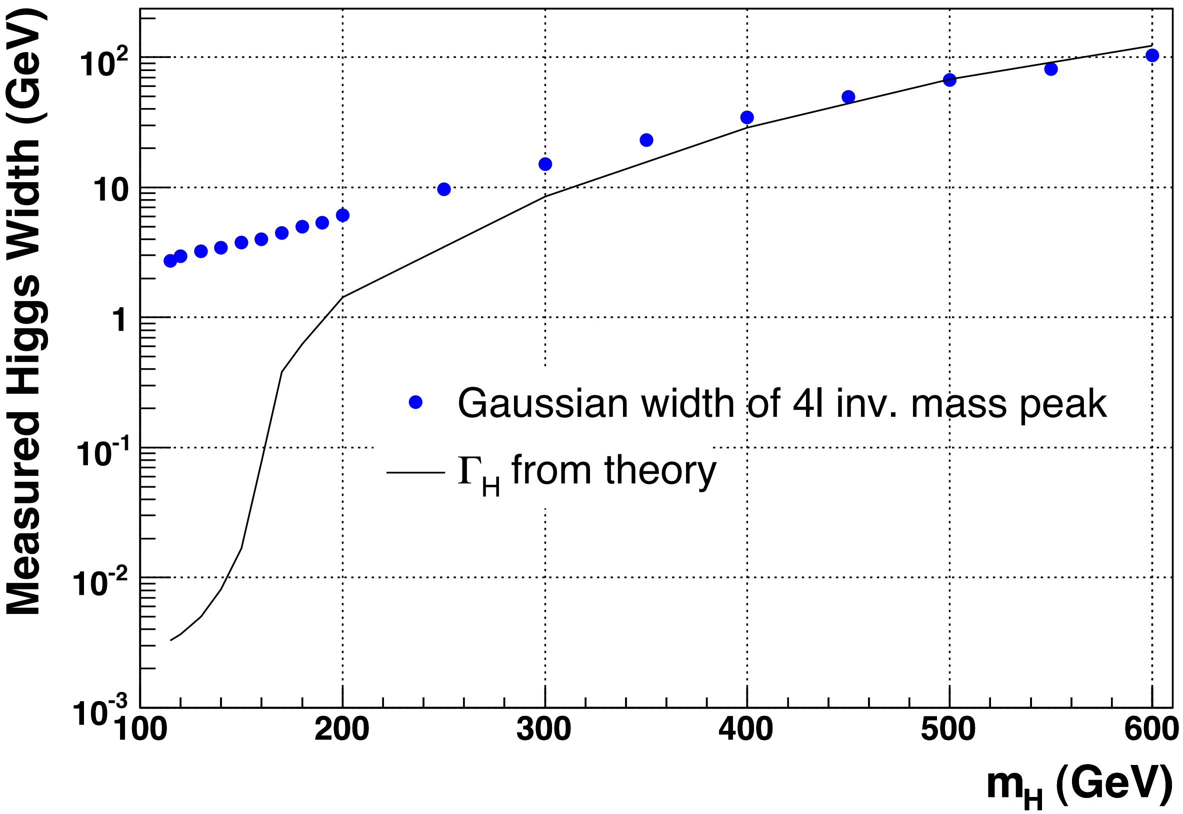
Dührssen, Heinemeyer, HEL, Rainwater, Weiglein, & Zeppenfeld, PRD70, 113009 (2004)

- 10%–50%+ uncertainties on couplings-squared.
- Systematic uncertainties are important.

This talk: can we make model-independent measurements?

$$\mathrm{Rate}_{ij} = a^2 \sigma_i^{\mathrm{SM}} \frac{a^2 \Gamma_j^{\mathrm{SM}}}{a^2 \Gamma_{\mathrm{tot}}^{\mathrm{SM}} + \Gamma_{\mathrm{new}}}$$

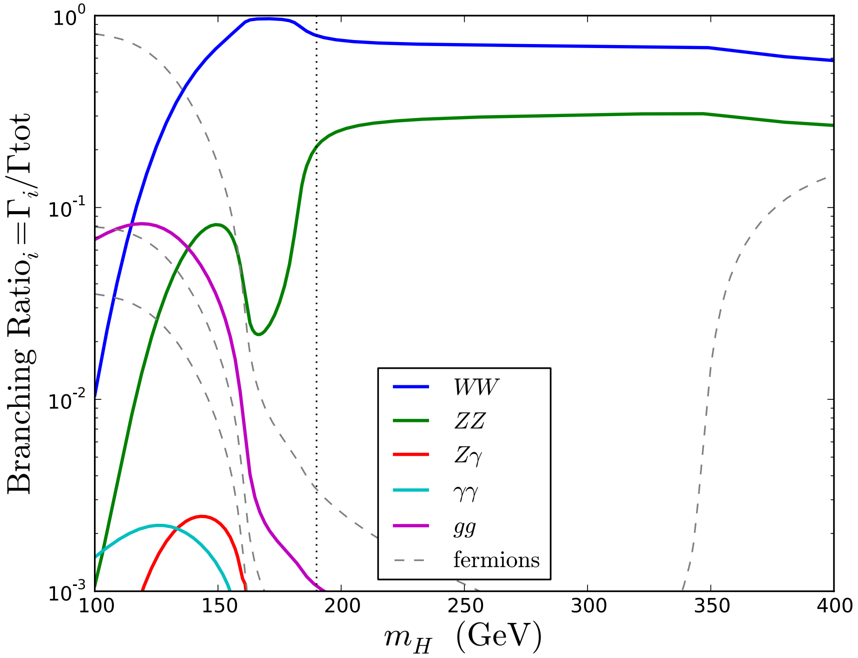
Consider extraction of Higgs couplings when Higgs total width is a directly measurable observable.



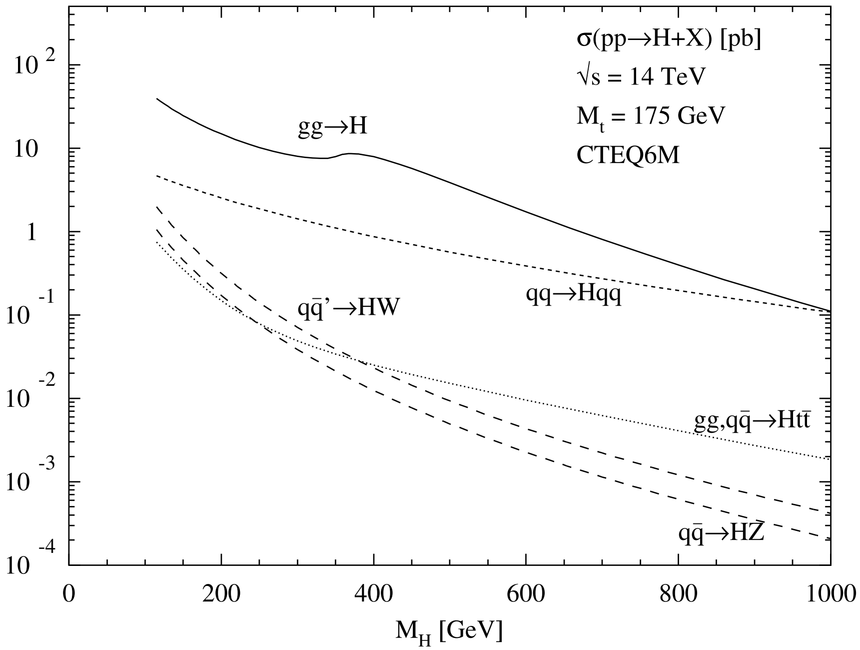
We study $M_H = 190$ GeV.

Method applicable also at higher Higgs masses.

CMS TDR (2006), Vol. 2 (Physics), chap. 10



SM Higgs BRs from HDECAY



CMS TDR (2006)

$M_H = 190$ GeV:

- Decays: only expect to be able to observe WW, ZZ
- Production: gluon fusion (GF), vector boson fusion (VBF)

Total width and rate measurement studies taken from literature (mix of CMS and ATLAS).

- All uncertainties statistical only.
- All studies were for 30 fb^{-1} at 1 detector at 14 TeV.
- We scale by $\sqrt{3/10}$ for 100 fb^{-1} estimate.

Total width:

17.6% for 30 fb^{-1}, 9.6% for 100 fb^{-1} CMS TDR (2006), Vol. 2 (Physics)

Rates:

Production	Decay	30 fb^{-1}	100 fb^{-1}	"contamination"	
GF	$ZZ \to 4\ell$	14%	7.9%	VBF $\sim$ 14%	[a]
VBF	$ZZ \to 4\ell$	24%	13%	GF $\sim$ 21%	[a]
GF	$WW \to \ell\ell p_T^{\rm miss}$	9.6%	5.3%	VBF $\sim$ 2.8%	[a]
VBF	$WW \to e\mu p_T^{\rm miss}$	14%	7.6%	GF $\sim$ 7.8%	[a]
VBF	$WW \to (ee,\mu\mu) p_T^{\rm miss}$	15%	8.1%	GF $\sim$ 7.2%	[a]
VBF	$WW \to \ell\nu jj$	16%	8.9%	(none)	[b]

[a] Dührssen, ATL-PHYS-2003-030 [b] Pi et al, CMS-NOTE-2006-092

We use statistical uncertainties only, no systematics! Extracted parameters are at a level of precision that we do expect systematic uncertainties to be important.

Parametrization of new physics:

$$\Gamma_{\rm tot} = \Gamma_W + \Gamma_Z + \Gamma_{\rm new}$$
$$\Gamma_W = \bar{g}_W^2 \Gamma_W^{\rm SM} \qquad \Gamma_Z = \bar{g}_Z^2 \Gamma_Z^{\rm SM} \qquad \sigma_{\rm GF} = \bar{g}_g^2 \sigma_{\rm GF}^{\rm SM}$$
$$\sigma_{\rm VBF} = [0.73 \bar{g}_W^2 + (1 - 0.73) \bar{g}_Z^2] \sigma_{\rm VBF}^{\rm SM}$$

How we do our fits:

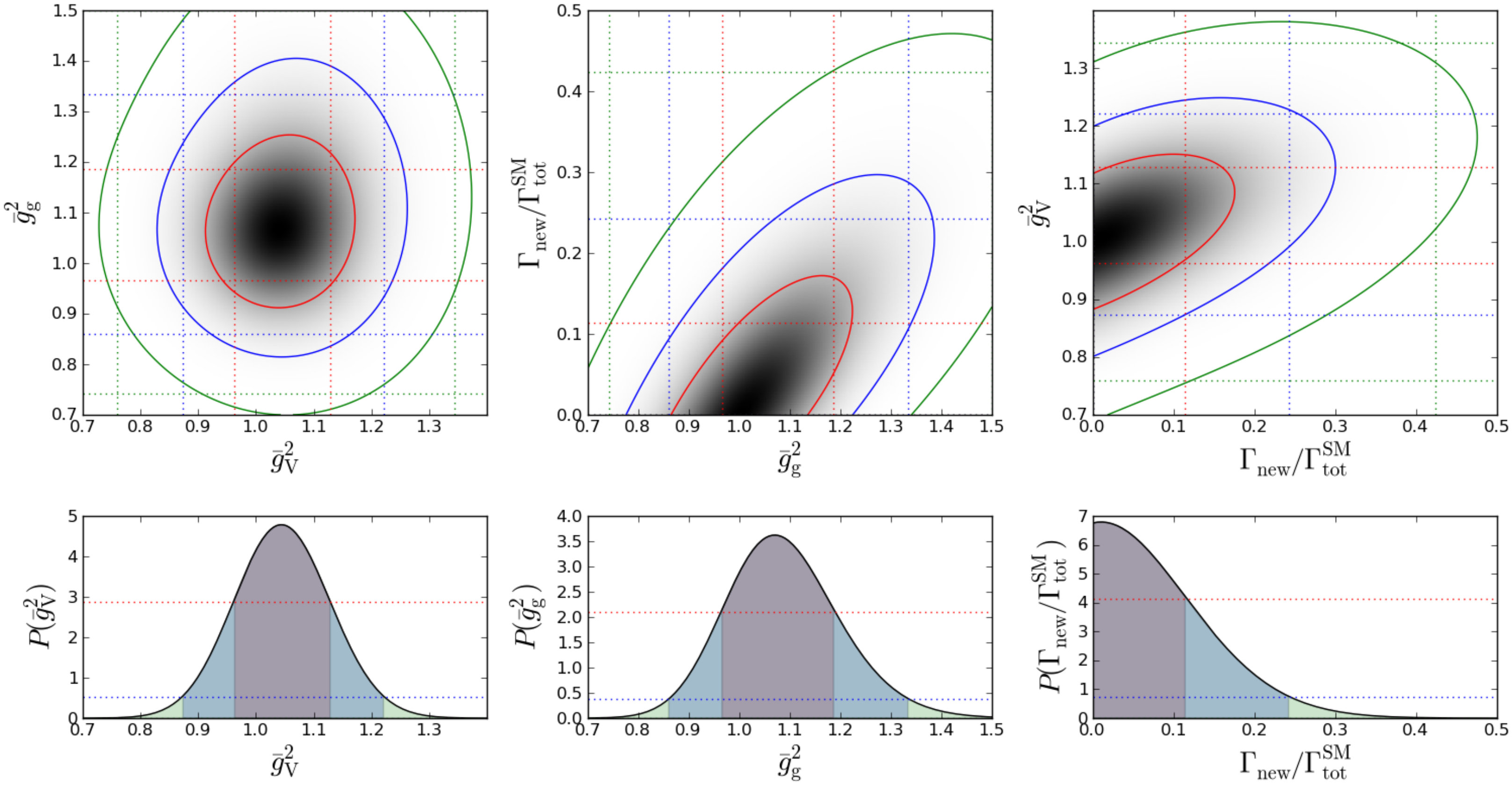
- Vary parameters, compute χ^2 from 7 observables assuming SM for central value, compute probability density $P = N e^{-\chi^2/2}$.
- Project onto 2 or 1 dimensions by numerically integrating P.
- Find P values that enclose 68, 95, 99% of probability.

Two sets of fits:

3-parameter: $\bar{g}_V^2 \equiv \bar{g}_W^2 = \bar{g}_Z^2$, $\bar{g}_g^2$, $\Gamma_{\rm new}/\Gamma_{\rm tot}^{\rm SM}$
4-parameter: $R \equiv \bar{g}_Z^2/\bar{g}_W^2$, $\bar{g}_W^2$, $\bar{g}_g^2$, $\Gamma_{\rm new}/\Gamma_{\rm tot}^{\rm SM}$.

Results: 3-parameter fit, 30 fb^{-1}

$\bar g_V^2 \equiv \bar g_W^2 = \bar g_Z^2$, $\bar g_g^2$, $\Gamma_{\rm new}/\Gamma_{\rm tot}^{\rm SM}$

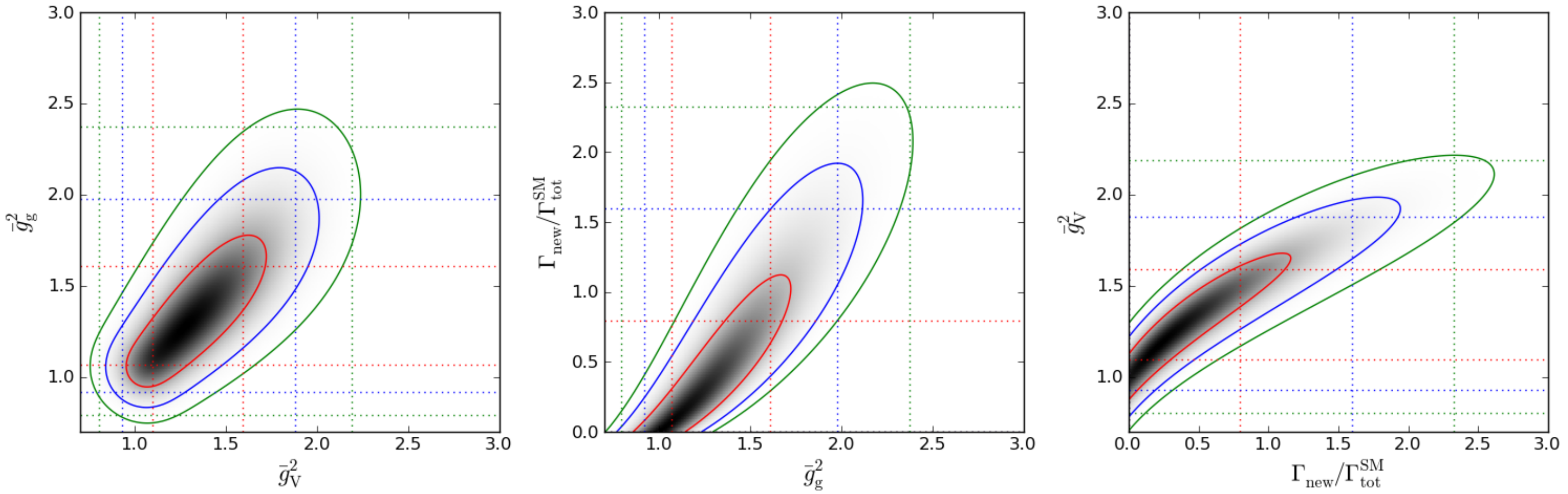


$\delta \bar g_V^2 \simeq 8\%$, $\delta \bar g_g^2 \simeq 11\%$, $\Gamma_{\rm new}/\Gamma_{\rm tot}^{\rm SM} \lesssim 24\%$ at 95% CL

Change 17.6% → 100% uncertainty on total width measurement: reopen the "flat direction"

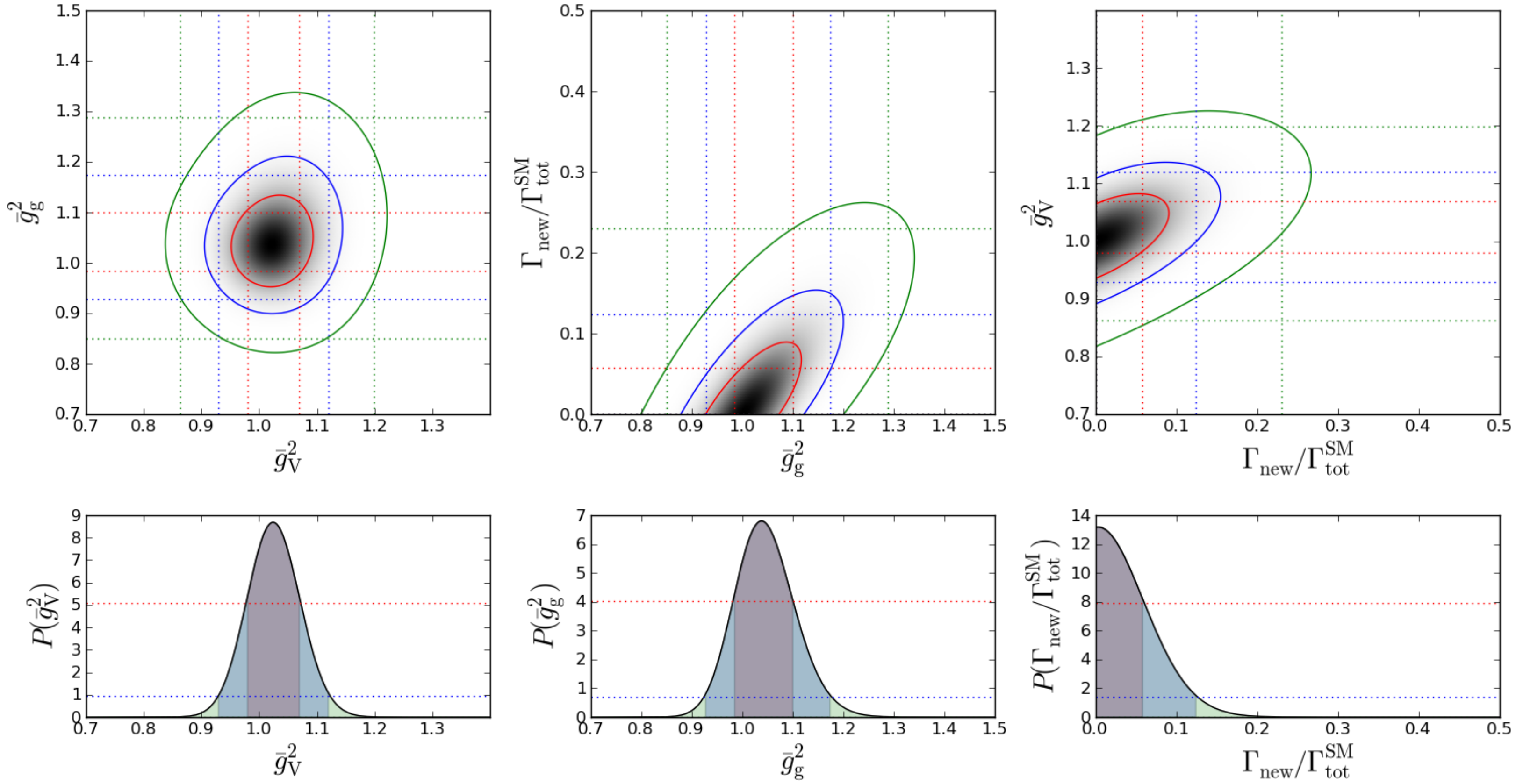
(3-parameter fit, 30 fb^{-1})

$\bar{g}_V^2 \equiv \bar{g}_W^2 = \bar{g}_Z^2$, $\bar{g}_g^2$, $\Gamma_{\text{new}}/\Gamma_{\text{tot}}^{\text{SM}}$



Results: 3-parameter fit, 100 fb^{-1}

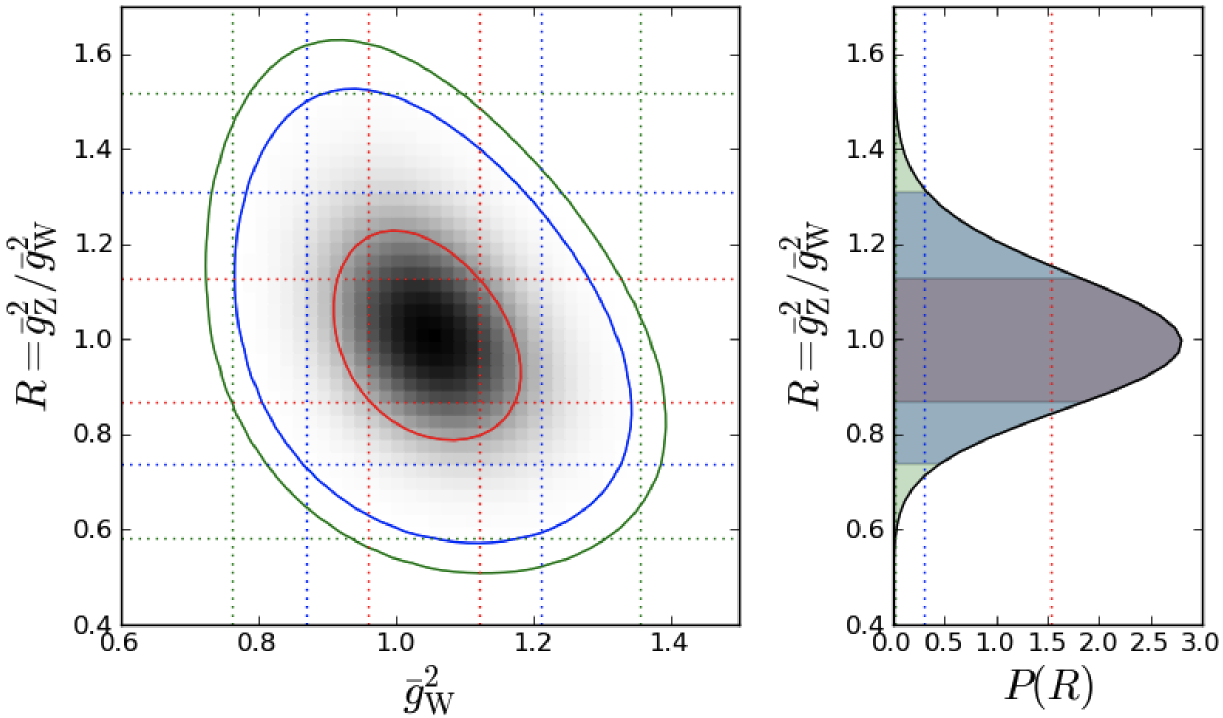
$\bar{g}_V^2 \equiv \bar{g}_W^2 = \bar{g}_Z^2$, $\bar{g}_g^2$, $\Gamma_{\rm new}/\Gamma_{\rm tot}^{\rm SM}$



$\delta\bar{g}_V^2 \simeq 4.5\%$, $\delta\bar{g}_g^2 \simeq 5.8\%$, $\Gamma_{\rm new}/\Gamma_{\rm tot} \lesssim 12\%$ at 95% CL

Results: 4-parameter fit, 30 fb^{-1}

$R \equiv \bar{g}_Z^2/\bar{g}_W^2$, $\bar{g}_W^2$, $\bar{g}_g^2$, $\Gamma_{\text{new}}/\Gamma_{\text{tot}}^{\text{SM}}$



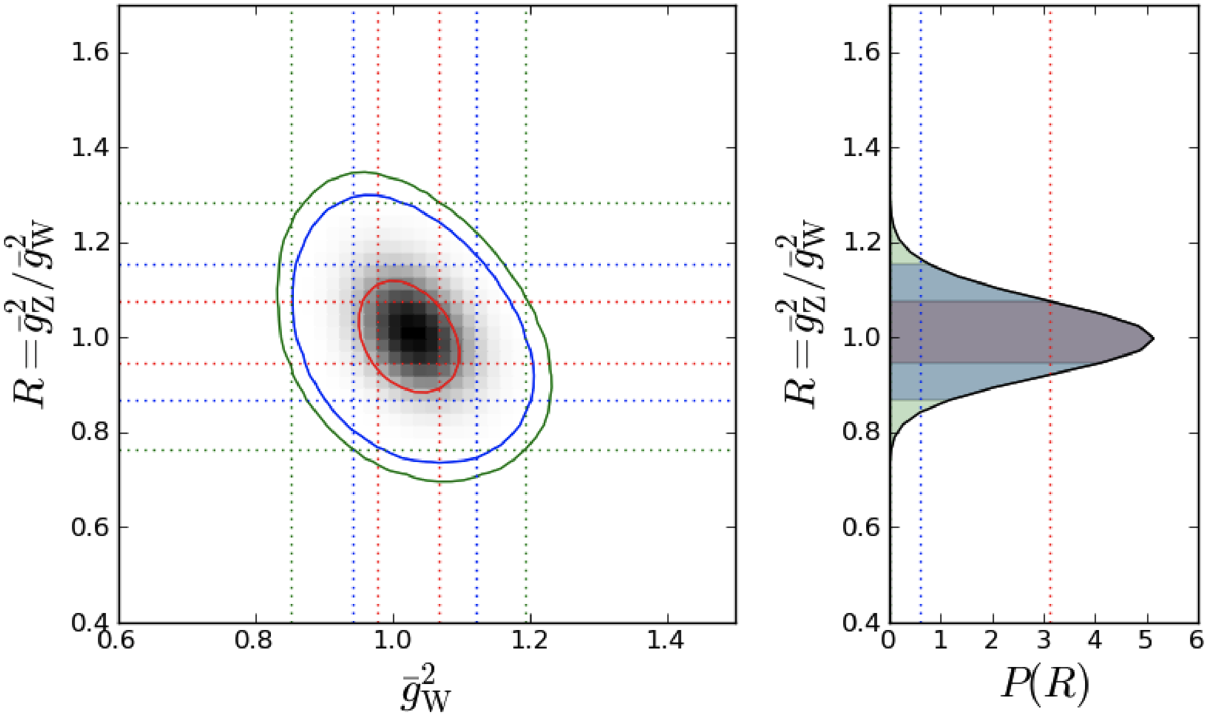
$\delta R \simeq 13\%$:

Compare 14% from ratios of rates to ZZ and WW final states.

$\bar{g}_W^2$ measurement not significantly degraded compared to 3-parameter $\bar{g}_V^2$ fit.

Results: 4-parameter fit, 100 fb^{-1}

$R \equiv \bar{g}_Z^2/\bar{g}_W^2$, $\bar{g}_W^2$, $\bar{g}_g^2$, $\Gamma_{\rm new}/\Gamma_{\rm tot}^{\rm SM}$



$\delta R \simeq$ 6.5%:

Compare 7.8% from ratios of rates to ZZ and WW final states.

$\bar{g}_W^2$ measurement not significantly degraded compared to 3-parameter $\bar{g}_V^2$ fit.

Conclusions

3-param fit	30 fb^{-1}	100 fb^{-1}	
$\bar{g}_V^2$	8%	4.5%	(1σ)
$\bar{g}_g^2$	11%	5.8%	(1σ)
$\Gamma_{\rm new}/\Gamma_{\rm tot}^{\rm SM}$	$< 24\%$	$< 12\%$	(95% CL)

4-param fit	30 fb^{-1}	100 fb^{-1}	
$R \equiv \bar{g}_Z^2/\bar{g}_W^2$	13%	6.5%	(1σ)
$\bar{g}_W^2$	8%	4.5%	(1σ)

Inclusion of $\Gamma_{\rm tot}$ measurement ($M_H \gtrsim 190$ GeV) allows model-independent Higgs coupling extraction at LHC.

No systematics included—will be important at this precision.

Compare ILC ($M_H = 190$ GeV):
$\bar{g}_W^2$, $\bar{g}_Z^2$ comparable, but real value-added is fermion couplings:
$t\bar{t}H$: $\delta\bar{g}_t^2 \sim 20\%$ hep-ph/0604034, 1000 fb^{-1} at $\sqrt{s} = 800$ GeV
$H \to b\bar{b}$: $\delta\bar{g}_b^2 \sim 14\%$ hep-ph/0211461, 500–1000 fb^{-1} at $\sqrt{s} = 500$–800 GeV