(Inverse) Higgs Phenomenology at LHC

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“LHC Inverse Problem” workshop @ Ann Arbor

This talk is based on collaborations and discussions with
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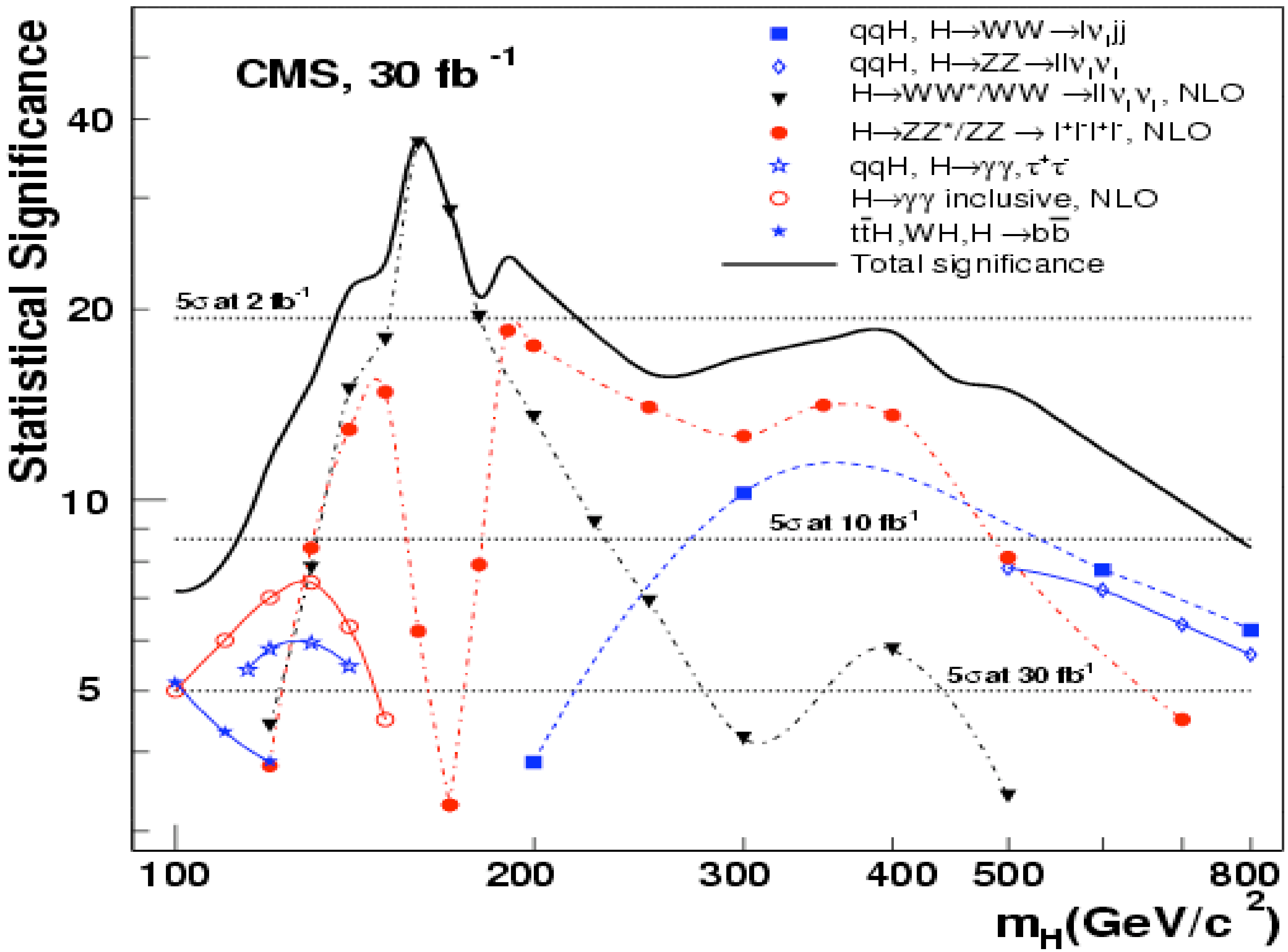
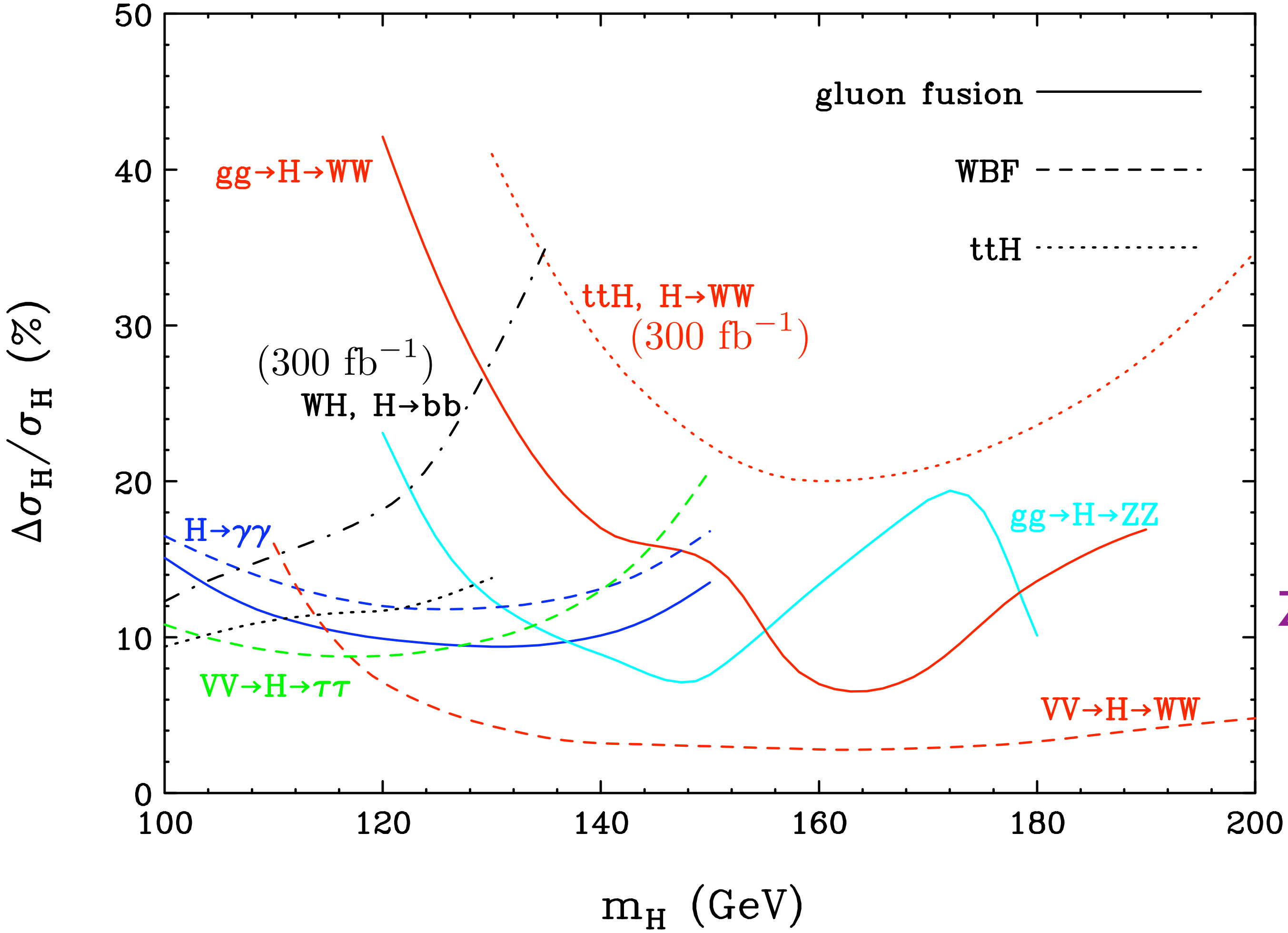
✦ Introduction

LHC experiments have the great potential to discover a Higgs boson in various channels.



In physics beyond the SM (SUSY, Little Higgs etc), we expect some non-SM Higgs couplings.

Can we extract any information on new physics from Higgs data?



Expected relative error on the determination of $\sigma \times \mathrm{BR}$ for various Higgs search channels at the LHC with 200 fb^{-1} of data

Zeppenfeld hep-ph/0203123

Zeppenfeld et al, hep-ph/0002036

Duhrssen et al, hep-ph/0406323

Outline

✦ Introduction

✦ Higgs interactions in new physics (NP) models

MSSM, Littlest Higgs model with T-parity

✦ Constraint on NP parameters from Higgs data

χ^2 analysis using Higgs $\sigma \times \mathrm{BR}$ data

- Littlest Higgs model with T-parity

new particle mass scale f

- MSSM $\beta, \ \alpha, \ \cdots$

(very preliminary)

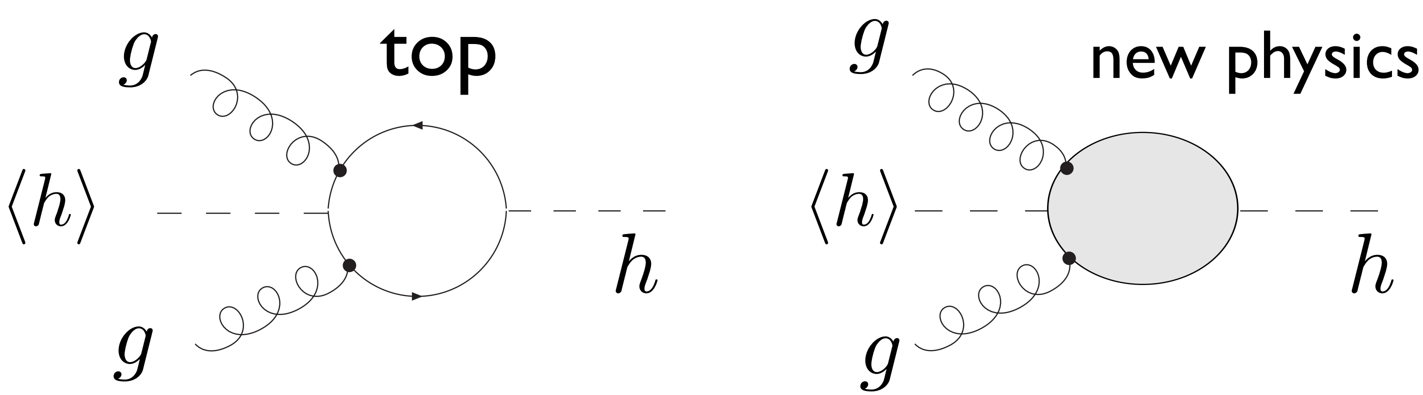
✦ Summary

✦ Higgs interactions in new physics models

- Solution to "naturalness problem" of Higgs mass

If there is "new physics" which cancels the Λ^2 induced by top,

the "new Physics" can affect gluon fusion process.

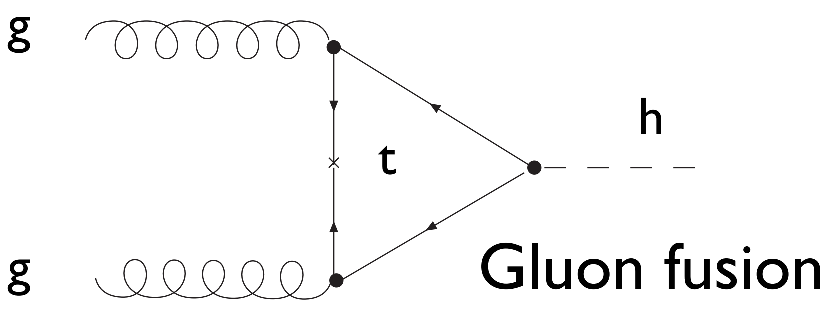


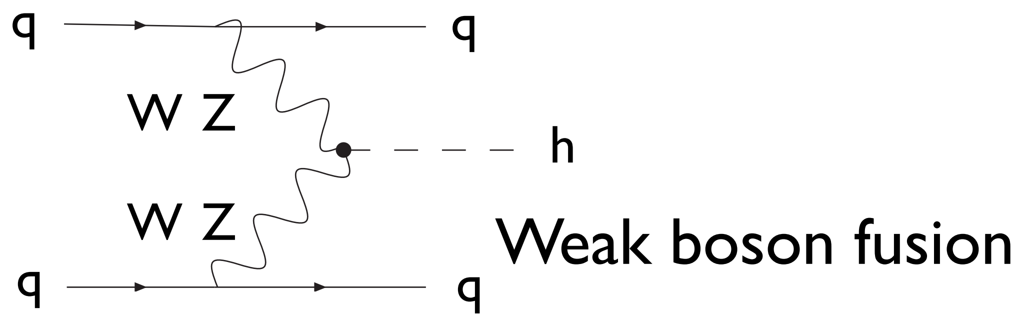
MSSM --- light stop (gluophobic scenario)

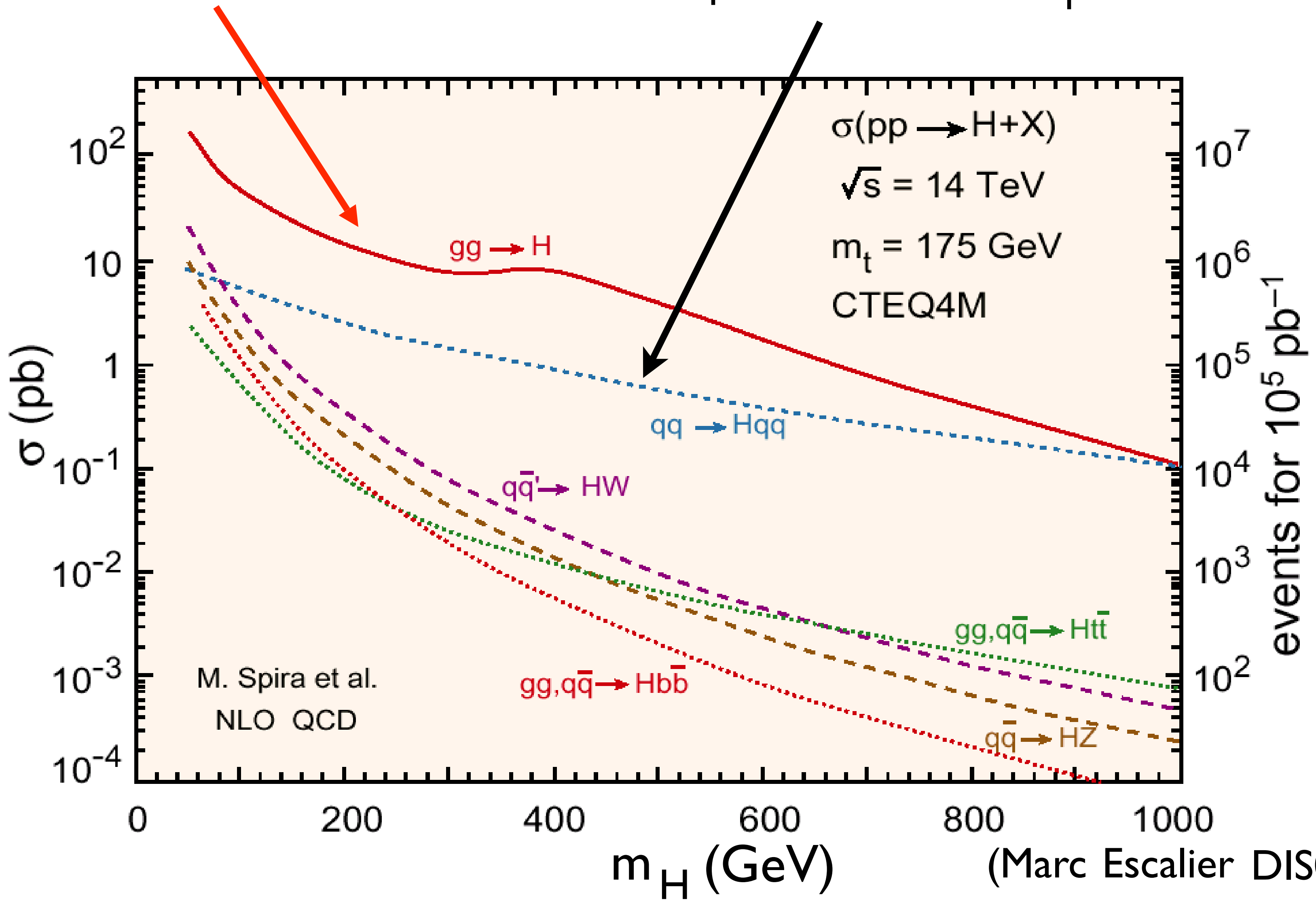
Little Higgs --- fermionic partner of top etc

It can affect the SM like Higgs boson search at LHC

Note: SM Higgs production at LHC







(Marc Escalier DIS05)

- Higgs sector can be modified

MSSM ---- two Higgs doublet model

tree level couplings of the lightest Higgs is modified

e.g. $\frac{g_{hdd}}{g_{hdd}^{\rm SM}} = -\frac{\sin\alpha}{\cos\beta}$ it can be larger one

$g_{hdd}/g_{hdd}^{\rm SM} \simeq 1.5$ for m_h max scenario

Higgs production and decay can be very different from the SM prediction

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Higgs interactions

gauge bosons and fermions

$$\mathcal{L}_{eff} = -g_{hVV} h V_\mu^\dagger V^\mu - g_{hff} h \bar{f} f$$

$$g_{hVV}/g_{hVV}^{\rm SM} = \gamma_V(A, B, \cdots), \; g_{hff}/g_{hff}^{\rm SM} = \gamma_f(A, B, \cdots)$$

gluon and photon

$$\Gamma_{gg}/\Gamma_{gg}^{\rm SM} = 1 + \delta_{gg}(A, B, \cdots), \quad \Gamma_{\gamma\gamma}/\Gamma_{\gamma\gamma}^{\rm SM} = 1 + \delta_{\gamma\gamma}(A, B, \cdots)$$

A,B,... are parameters of the new physics model

Higgs production and decay data constrain (hopefully measure) the parameters of the theory (A,B,...)

Example 1: MSSM

MSSM lightest Higgs boson couplings

- gauge boson

$$\frac{g_{hVV}}{g_{hVV}^{\rm SM}} = \sin(\beta-\alpha) \text{ for } V = W, Z$$

$\tan\beta = v_u/v_d$

α :Higgs mixing angle

- fermion

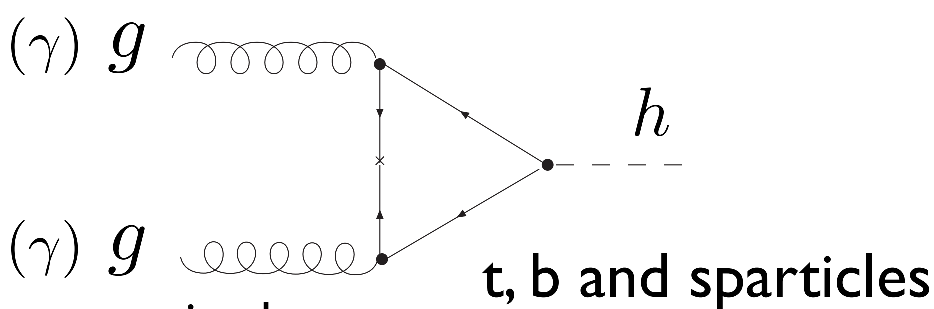
$$\frac{g_{huu}}{g_{huu}^{\rm SM}} = \frac{\cos\alpha}{\sin\beta} \qquad \frac{g_{hdd}}{g_{hdd}^{\rm SM}} = -\frac{\sin\alpha}{\cos\beta}$$

$$\frac{g_{hbb}}{g_{hbb}^{\rm SM}} = -\frac{\sin\alpha}{\cos\beta}(1+\delta_b) \text{ for bottom} \qquad (b\to\tau \text{ for tau})$$

$$\frac{g_{htt}}{g_{htt}^{\rm SM}} = \frac{\cos\alpha}{\sin\beta}(1+\delta_t) \text{ for top}$$

- gluon and photon

$$\frac{\Gamma_{gg}}{\Gamma_{gg}^{\rm SM}} = \frac{\sigma_{gg}}{\sigma_{gg}^{\rm SM}} = 1+\delta_{gg}$$



Similarly, photon-Higgs coupling is parametrized

$\alpha,\ \beta,\ \delta_p\ (p = b,\ t,\ \tau\ , gg \text{ and } \gamma\gamma)$ are (effective) parameters for Higgs couplings

Example 2: Littlest Higgs model with T-parity

- SU(5)/SO(5) non-linear sigma model

Arkani-Hamed, Cohen, Katz, Nelson hep-ph/0206021

$$SU(5) \xrightarrow{f} SO(5) \qquad \mathbf{1_0} \oplus \mathbf{3_0} \oplus \mathbf{2_{\pm 1/2}} \oplus \mathbf{3_{\pm 1}}$$

$$[SU(2) \times U(1)]_1 \times [SU(2) \times U(1)]_2 \longrightarrow SU(2) \times U(1)$$

- Collective symmetry breaking mechanism

Large SM one-loop quadratic divergences in Higgs mass are canceled by new particles

- T-parity Cheng, Low hep-ph/0308199

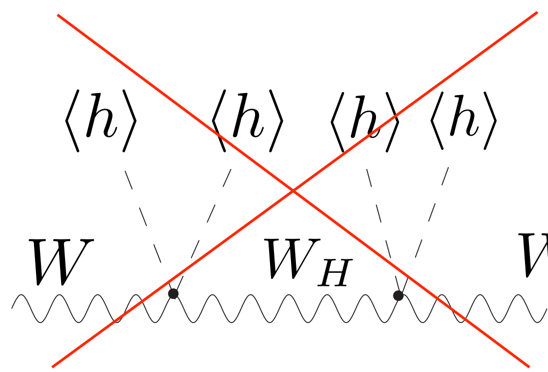
$$SU(2)_1 \times U(1)_1 \leftrightarrow SU(2)_2 \times U(1)_2$$

$$\text{SM particles} \rightarrow +\text{SM particles}$$

$$(W_H,\ Z_H,\ A_H,\ \Phi) \rightarrow -(W_H,\ Z_H,\ A_H,\ \Phi)$$

(heavy gauge bosons and Higgs)

$q_- \longrightarrow -q_-$ (T-odd doublet fermions)

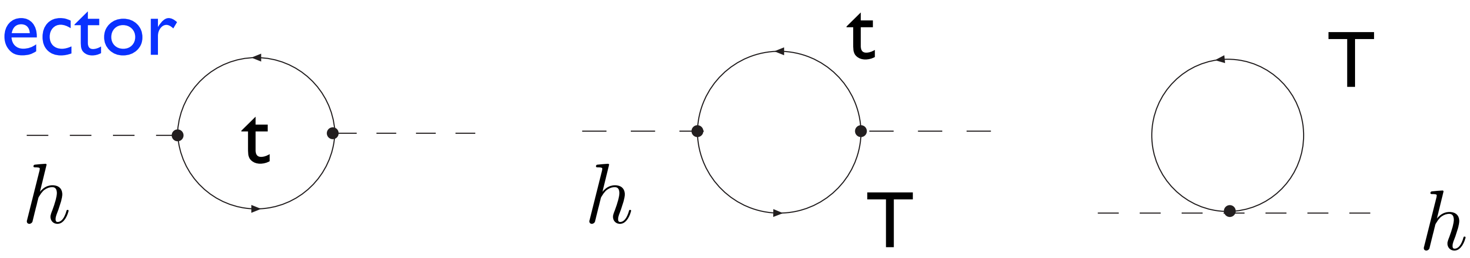


✳ Contributions to EW observables are loop suppressed.
The new particle scale f can be much lower than 1 TeV.

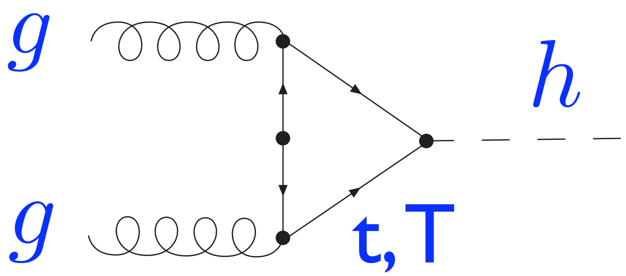
✳ The lightest T-odd particle can be a good dark matter candidate

Gluon fusion process in Littlest Higgs model with T-parity

Top sector



The large quadratic divergence induced by top is canceled by the heavy fermionic partner of the top-quark, T

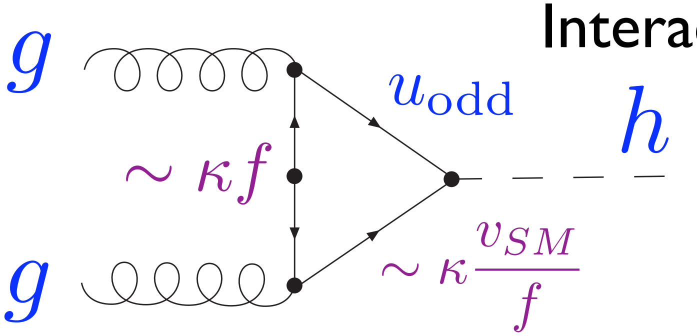


$$\frac{\delta\sigma_{gg\to h}(\text{top sector})}{\sigma_{gg\to h}(\text{top in SM})} \simeq -\frac{3}{2}\frac{v_{SM}^2}{f^2}$$

Han, Logan, McElrath, Wang hep-ph/0302188

T-odd doublet quark sector

Low, hep-ph/0409025, Hubisz et al hep-ph/0411264



Interaction which generates T-odd doublet quarks induces the Higgs interaction

$$\frac{\delta\sigma_{gg\to h}(\text{T odd fermions})}{\sigma_{gg\to h}(\text{top in SM})} \simeq -\frac{3}{2}\frac{v_{SM}^2}{f^2}$$

Chen, Tobe, Yuan, hep-ph/0602211

Gluon fusion

Chen, Tobe, Yuan, hep-ph/0602211

$$\frac{\delta\sigma_{gg\to h}}{\sigma^{\rm SM}_{gg\to h}} \simeq -3\frac{v_{SM}^2}{f^2} \simeq \begin{cases} -37\% \text{ for } f = 700 \text{ GeV}, \\ -18\% \text{ for } f = 1000 \text{ GeV}. \end{cases}$$

it could be significantly suppressed

Higgs couplings in Littlest Higgs model with T-parity

- gauge boson (V=W, Z)

$$\frac{g_{hVV}}{g^{\rm SM}_{hVV}} \simeq 1 - \frac{1}{4}\frac{v_{SM}^2}{f^2} \simeq \begin{cases} 0.97 \text{ for } f = 700 \text{ GeV}, \\ 0.98 \text{ for } f = 1000 \text{ GeV}. \end{cases}$$

- fermion

$$\frac{g_{huu}}{g^{\rm SM}_{huu}} \simeq 1 - \frac{3}{4}\frac{v_{SM}^2}{f^2} \simeq \begin{cases} 0.90 \text{ for } f = 700 \text{ GeV}, \\ 0.95 \text{ for } f = 1000 \text{ GeV}. \end{cases}$$

$$\frac{g_{htt}}{g^{\rm SM}_{htt}} \simeq 1 - \frac{1}{2}\frac{v_{SM}^2}{f^2} \simeq \begin{cases} 0.94 \text{ for } f = 700 \text{ GeV}, \\ 0.97 \text{ for } f = 1000 \text{ GeV}. \end{cases} \quad (\lambda_1 = \lambda_2)$$

$$\frac{g_{hdd}}{g^{\rm SM}_{hdd}} \simeq 1 - \frac{1}{4}\frac{v_{SM}^2}{f^2} \simeq \begin{cases} 0.97 \text{ for } f = 700 \text{ GeV}, \\ 0.99 \text{ for } f = 1000 \text{ GeV}, \end{cases} \quad \text{for Case A},$$

$$\simeq 1 - \frac{5}{4}\frac{v_{SM}^2}{f^2} \simeq \begin{cases} 0.84 \text{ for } f = 700 \text{ GeV}, \\ 0.92 \text{ for } f = 1000 \text{ GeV}, \end{cases} \quad \text{for Case B}.$$

(We consider the same Yukawa structures in lepton sector, as in quark sector.)

Higgs couplings are function of the scale "f"

$$R_{\sigma(X)} = \frac{\sigma^{\rm LH}(X)}{\sigma^{\rm SM}(X)} \qquad R_{{\rm BR}(Y)} = \frac{{\rm BR}^{\rm LH}(Y)}{{\rm BR}^{\rm SM}(Y)}$$

$$R_{\sigma(X)} \times R_{{\rm BR}(Y)} \quad \text{for } f = (600,\ 700,\ 1000)\ \text{GeV}$$

$m_h = 120$ GeV	$R_{{\rm BR}(\gamma\gamma)}$	$R_{{\rm BR}(\tau\tau)}$	$R_{{\rm BR}(b\bar{b})}$	$R_{{\rm BR}(VV)}$
$R_{\sigma(gg)}$ (Case A)	0.57, 0.68, 0.84	0.56, 0.67, 0.83	–	0.55, 0.66, 0.83
(Case B)	0.81, 0.86, 0.93	0.51, 0.63, 0.81	–	0.78, 0.84, 0.92
$R_{\sigma(VV)}$ (Case A)	0.97, 0.98, 0.99	0.95, 0.96, 0.98	–	0.94, 0.96, 0.98
(Case B)	1.34, 1.22, 1.09	0.84, 0.89, 0.95	–	1.30, 1.19, 1.08
$R_{\sigma(t\bar{t}h)}$ (Case A)	–	0.87, 0.90, 0.95	0.87, 0.90, 0.95	–
(Case B)	–	0.77, 0.83, 0.92	0.77, 0.83, 0.92	–
$R_{\sigma(Vh)}$ (Case A)	0.97, 0.98, 0.99	–	0.95, 0.96, 0.98	–
(Case B)	1.34, 1.22, 1.09	–	0.84, 0.89, 0.95	–
$m_h = 200$ GeV	$R_{{\rm BR}(\gamma\gamma)}$	$R_{{\rm BR}(\tau\tau)}$	$R_{{\rm BR}(b\bar{b})}$	$R_{{\rm BR}(VV)}$
$R_{\sigma(gg)}$ (Case A)	–	–	–	0.55, 0.67, 0.83
(Case B)	–	–	–	0.56, 0.67, 0.83
$R_{\sigma(VV)}$ (Case A)	–	–	–	0.90, 0.94, 0.97
(Case B)	–	–	–	0.90, 0.94, 0.97

- Higgs production via gluon fusion is suppressed.
- $\gamma\gamma,\ VV$ decay modes via weak boson fusion can be enhanced in small Higgs mass region in Case B.

✦Constraint on NP parameters from Higgs data (preliminary)

- Suppose LHC experiments find a Higgs in various channels and measure $\sigma \times \mathrm{BR}$
- The following errors on the determination of $\sigma_h = \sigma \times \mathrm{BR}$ for various Higgs search channels are assumed: Zeppenfeld, hep-ph/0203123

$\Delta\sigma_h/\sigma_h(\%)$	$\gamma\gamma$ (decay)	$\tau\tau$	$b\bar{b}$	VV
gg (production)	9.9, 9.4	-	-	23.1, 12.4 (ZZ^*) 42.1, 26.0 (WW^*)
qqh	12.0, 11.9	8.8, 9.9	-	7.1, 4.3 (WW^*)
tth	-	17.0, 23.3	11.4, 14.3	$-$, 42.0 (WW^*)
Wh	-	-	19.0, 25.0	

for $m_h = 120$ and 130 GeV, respectively

gg	10%
qqh	4%
tth	15%
WH	7%

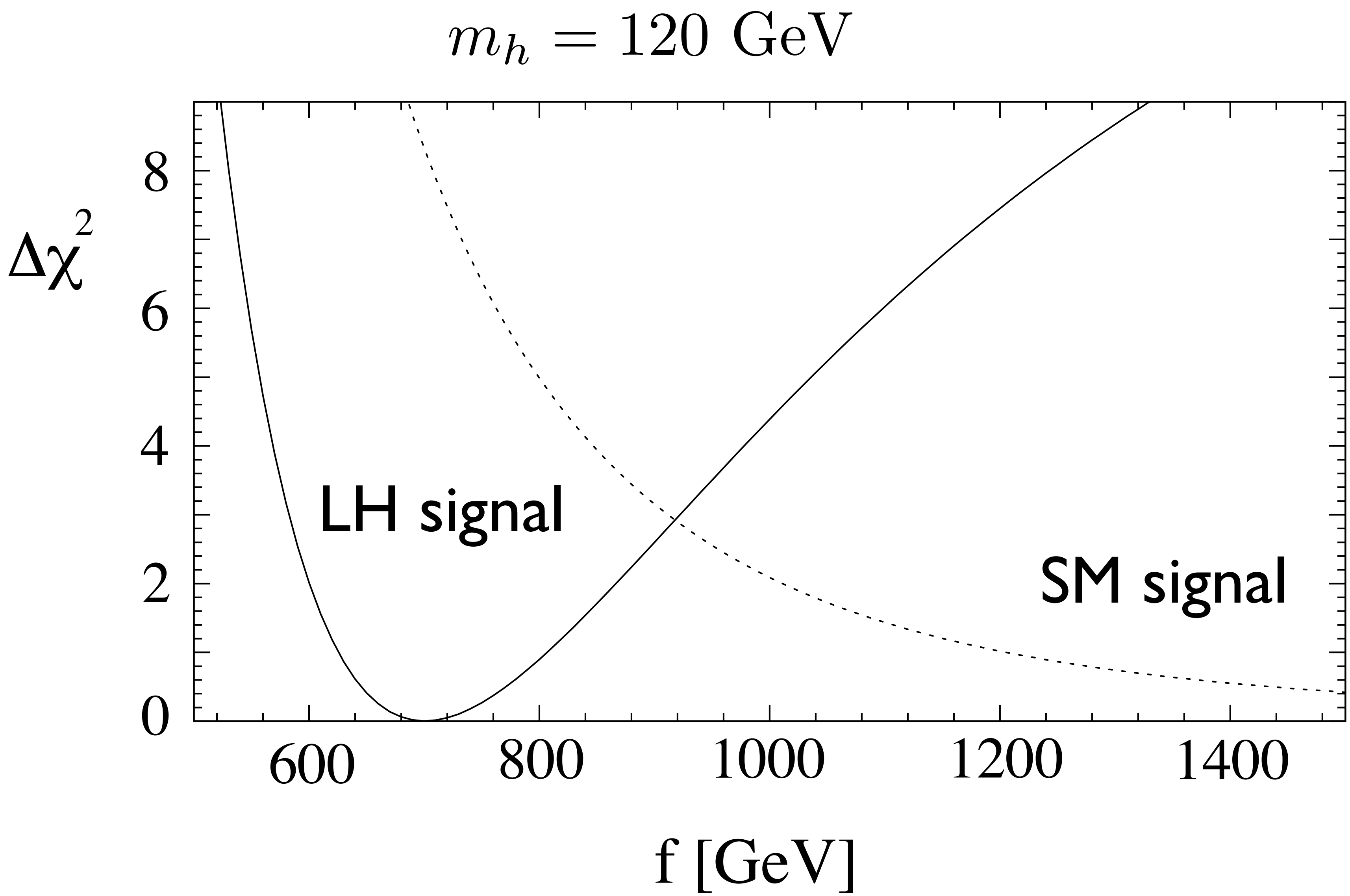
Theoretical QCD and PDF uncertainties on the various Higgs production channels.

Duhrssen et al, hep-ph/0406323

Anastasiou et al, hep-ph/0509014

- χ^2 analysis on $\sigma_h = \sigma \times \mathrm{BR}$
- Constraints on parameters of the models

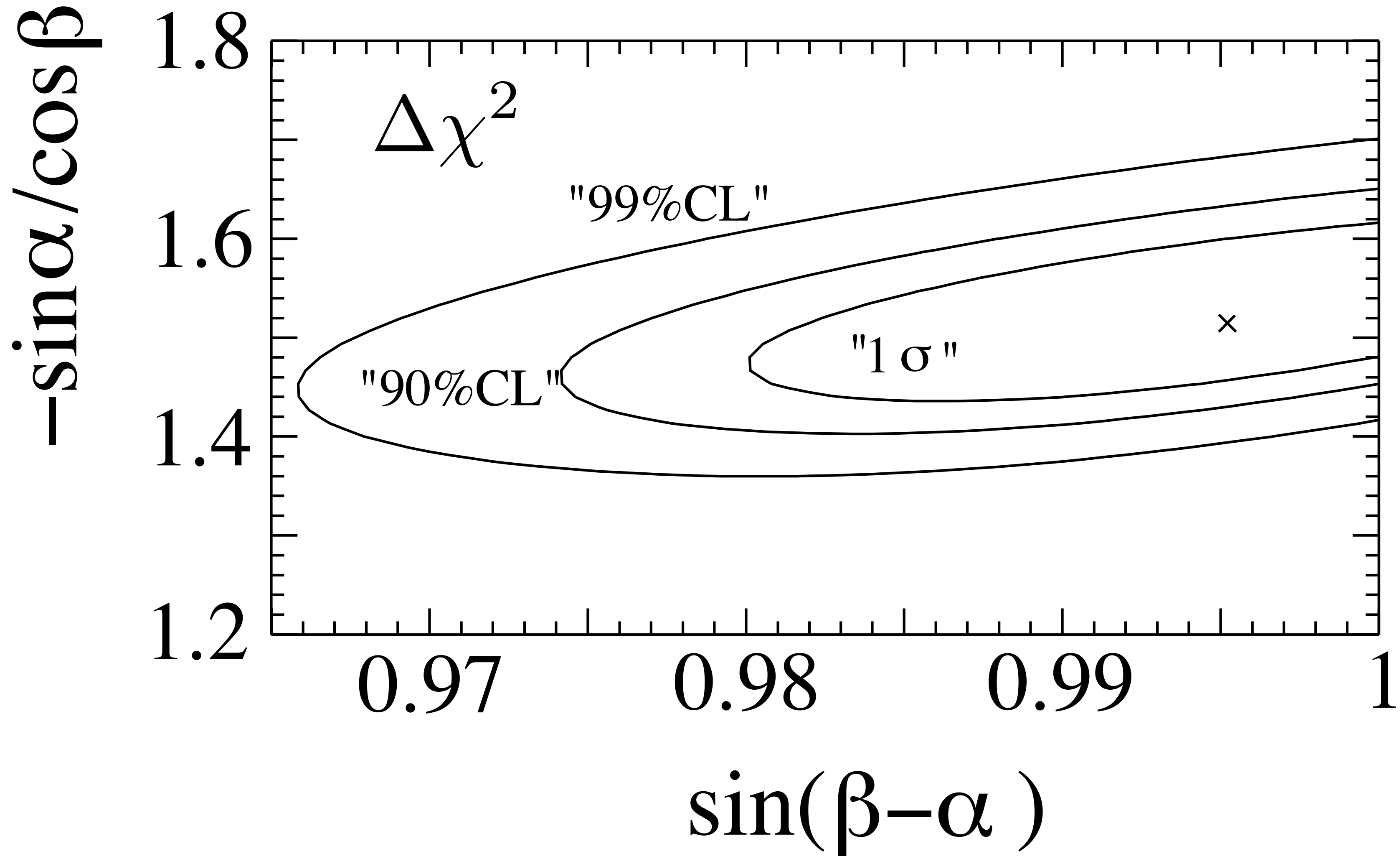
Littlest Higgs model with T-parity



LH signal : Littlest Higgs in Case A with f = 700 GeV

MSSM For simplicity,

$$\delta_b = \delta_t = \delta_{gg} = \delta_{\gamma\gamma} = 0$$



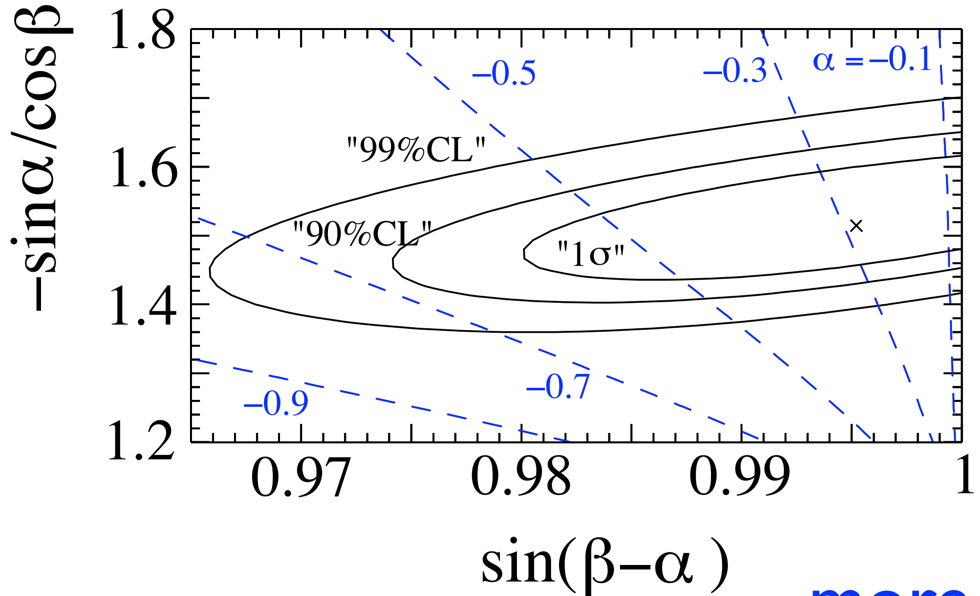
MSSM signal: mh max scenario with

$\tan\beta = 8$ and $m_A = 250$ GeV

$\sigma_h/\sigma_h^{\rm SM}$	$\gamma\gamma$ (decay)	$\tau\tau$	$b\bar{b}$	VV
gg (production)	0.52	-	-	0.54 (ZZ^*) 0.55 (WW^*)
qqh	0.54	1.3	-	0.57 (WW^*)
tth	-	1.3	1.3	0.56 (WW^*)
Wh	-	-	1.27	

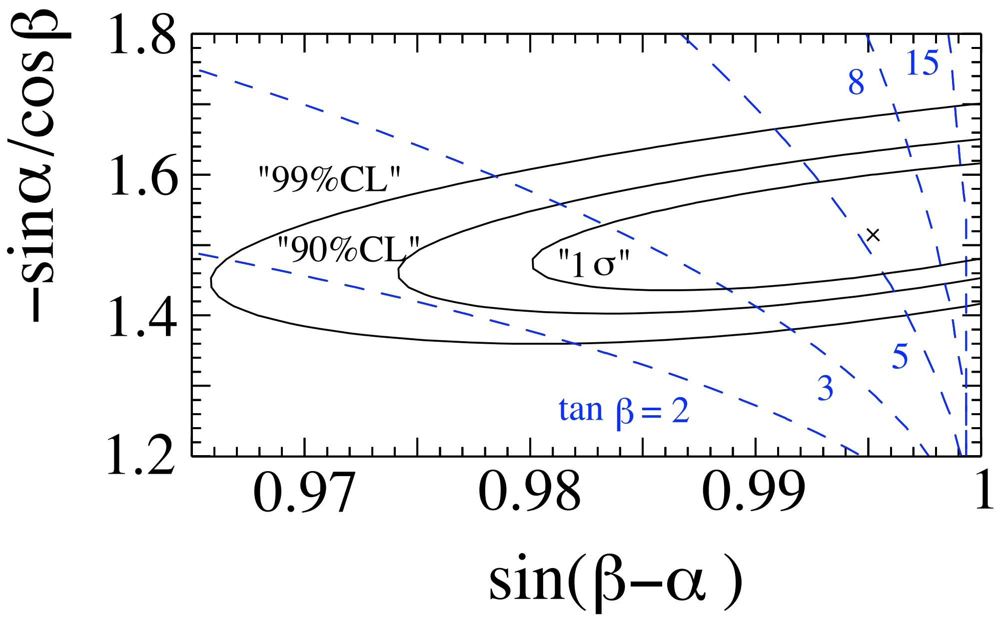
FeynHiggs

Table 1: $\sigma \times \mathrm{BR}/(\sigma \times \mathrm{BR})_{SM}$ in m_h max scenario with $tan\beta = 8$ and $m_A = 250$ GeV.



$\tan\beta$ and α

more fundamental parameters ?



It's difficult to constrain $\tan\beta$

✦ Summary

- LHC experiments have the great potential to discover a Higgs in various channels.
- We expect non-SM Higgs interaction in interesting new physics model (MSSM, Little Higgs etc).
- Higgs production and decay data might provide interesting information on new physics models.

Higgs physics at the LHC can be indirect search for new physics