Light scalar at LHC: the Higgs or the dilaton?

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hep-ph/0708:1463
(today)

Outline

- Why is the Higgs so similar to the dilaton?
- Conformal theories at the TeV scale
- Dilaton couplings:
  Higgs-like: fermions and W/Z
  Higgs-unlike: massless gauge bosons, self couplings
- The dilaton at colliders: LEP, LHC, ILC.
- Things to do ...

Why is the Higgs so similar to the dilaton?

Because the dilaton couples to $T^\mu_\mu = \sum_i m_i \overline{\psi}\psi + \ldots$

Because a light Higgs is also the dilaton

- SM interactions are approximately conformal down to the QCD scale
- Higgs mass term - explicit breaking
- Higgs VEV - spontaneous breaking

However, in general conformal invariance can be broken at a higher scale than the EW symmetry

$$\Lambda_{CFT} \sim 4\pi f$$

The breaking of conformal invariance triggers EWSB

$$\Lambda_{EW} \sim 4\pi v \leq \Lambda_{CFT}$$

The scales v and *f* are not the same, except for the Higgs

Conformal theories at the TeV scale

Classic example: walking technicolor
(some doubted that the dilaton would be light)

Things changed with AdS/CFT and RS model,
where there are plenty of examples of CFT's
that are spontaneously broken

There is no doubt a small parameter controlling
the dilaton mass exists in such theories

Dilaton couplings

Given the Lagrangian $\mathcal{L} = \sum_i g_i(\mu)\mathcal{O}_i(x),$

the divergence of the scale current is:

$$\partial_\mu S^\mu = \sum_i g_i(\mu)(d_i - 4)\mathcal{O}_i(x) + \sum_i \beta_i(g)\frac{\partial}{\partial g_i}\mathcal{L}$$

Including the dilaton field, $\chi(x)$, makes the Lagrangian formally scale invariant

$$g_i(\mu) \to g_i\left(\mu\frac{\chi}{f}\right)\left(\frac{\chi}{f}\right)^{4-d_i}$$

The electroweak sector:

$$\mathcal{L}_{EW} = \mathcal{L}_{\chi EW} + \mathcal{L}_{\psi} + \mathcal{L}_{Y}$$

EW chiral Lagragian — kinetic terms for fermions — Yukawa couplings

After replacing $\chi(x) \to f + \bar{\chi}(x)$

$$\mathcal{L} = \left(\frac{2\bar{\chi}}{f} + \frac{\bar{\chi}^2}{f^2}\right)\left[m_W^2 W_\mu^+ W^{-\mu} + \frac{1}{2} m_Z^2 Z_\mu Z^\mu\right] + \frac{\bar{\chi}}{f}\sum_\psi m_\psi \bar{\psi}\psi$$

(The usual Higgs couplings rescaled by $\dfrac{v}{f}$. Note only partial restoration of unitarity if $f > v$.)

Dilaton cubic self coupling

Suppose CS is explicitly broken: $\mathcal{L}_{CFT} + \lambda_{\mathcal{O}} \mathcal{O}(x)$

Usual spurion analysis gives
$$V(\chi) = \chi^4 \sum_{n=0}^{\infty} c_n(\Delta_{\mathcal{O}}) \left(\frac{\chi}{f}\right)^{n(\Delta_{\mathcal{O}}-4)}$$

$\Delta_{\mathcal{O}}$ ↔ $dim(\mathcal{O})$

There are two limits in which there is a small parameter
(a) $\lambda_{\mathcal{O}}$ small in units of *f*, (b) $|\Delta_{\mathcal{O}} - 4| \ll 1$

$$V(\bar{\chi}) = \frac{1}{2} m^2 \bar{\chi}^2 + \frac{\lambda}{3!} \frac{m^2}{f} \bar{\chi}^3 + \cdots$$

$$\lambda = \begin{cases} (\Delta_{\mathcal{O}} + 1) + \mathcal{O}(\lambda_{\mathcal{O}}) & \text{case (a)} \\ 5 + \mathcal{O}\left(|\Delta_{\mathcal{O}} - 4|\right) & \text{case (b)} \end{cases}$$

$$\lambda = \begin{cases} (\Delta_{\mathcal{O}} + 1) + \mathcal{O}(\lambda_{\mathcal{O}}) & \text{when } \lambda_{\mathcal{O}} \ll 1 \\ 5 + \mathcal{O}\left(|\Delta_{\mathcal{O}} - 4|\right) & \text{when } |\Delta_{\mathcal{O}} - 4| \ll 1 \end{cases}$$

The Higgs case, $\Delta_{\mathcal{O}} = 2$, checks out $\lambda = 3$

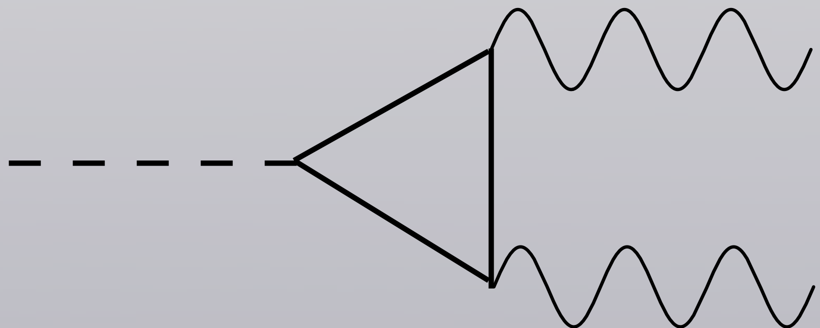
Irrelevant perturbations should not break conformal symmetry which implies an upper bound on the cubic

$$\lambda \leq 5$$

saturated for nearly marginal operators

Couplings to massless gauge bosons

At zero momentum the Higgs/dilaton couplings are related to the conformal anomaly



$$\mathcal{L}_{hGG} = \frac{\alpha_s}{8\pi} \sum_{\text{heavy}} b_0^i \frac{h}{v} (G^a_{\mu\nu})^2$$

If SM is embedded in a conformal theory

$$\sum_{\text{light}} b_0 + \sum_{\text{heavy}} b_0 = 0$$

$$\mathcal{L}_{\chi gg} = -\frac{\alpha_s}{8\pi} b_0^{\text{light}} \frac{\bar{\chi}}{f} (G^a_{\mu\nu})^2$$

- Large enhancement of the dilaton-glue coupling possible, an order of magnitude compared to SM Higgs
- The coupling to the photons may be suppressed
- Not a clean dilaton signature since Higgs couplings can be altered by heavy particles as well
- An exact result for the couplings obtained using conformal compensator

$$\mathcal{L}_{\chi gg} = -\frac{\beta(g)}{2g}\frac{\bar{\chi}}{f}(G^a_{\mu\nu})^2$$

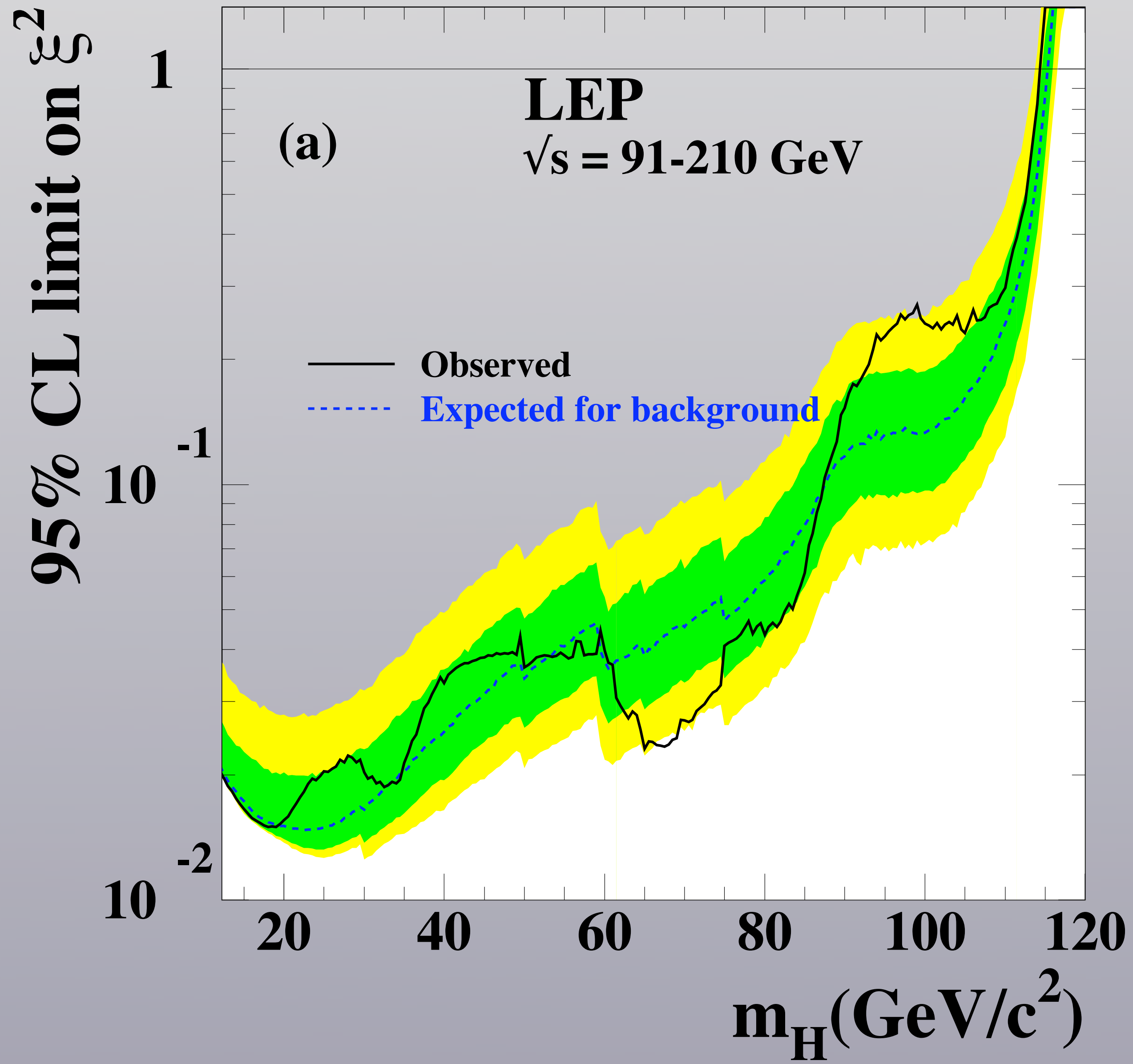
The dilaton at colliders

Branching ratios to fermions and WW, ZZ same as Higgs

The crucial parameters are *f* and *m*
complete Lagrangian also has three couplings: $\lambda,\ c_G,\ c_{EM}$

- LEP: bounds if $v^2/f^2 > 0.1 - 0.01$
- LHC: discovery that could be easier or harder than the Higgs case depending on the ratio *v/f* and the strength of the χgg, $\chi\gamma\gamma$ couplings, crude measurement of *v/f*
- ILC: precise measurements of f via couplings of gauge bosons, branching ratios, total width, a chance to measure the cubic

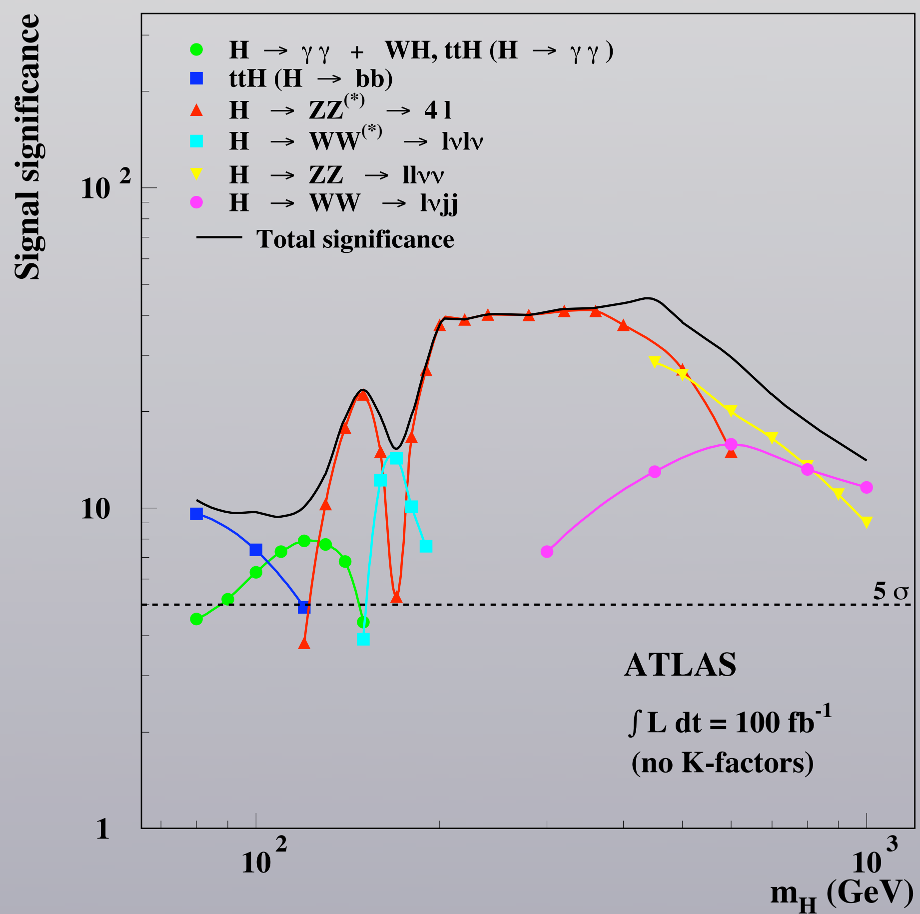
LEP bounds



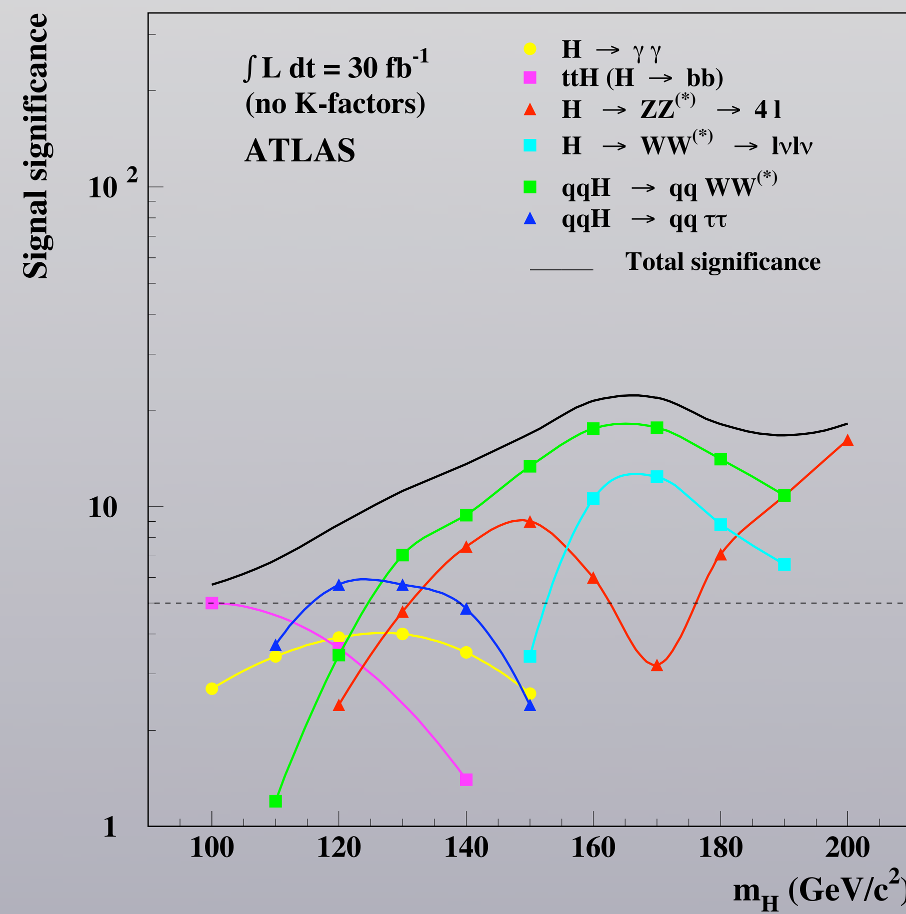
$$\xi = \frac{v}{f}$$

[LEP Higgs working group]

LHC Higgs reach (multiply by $c_G^2 \frac{v^2}{f^2}$)



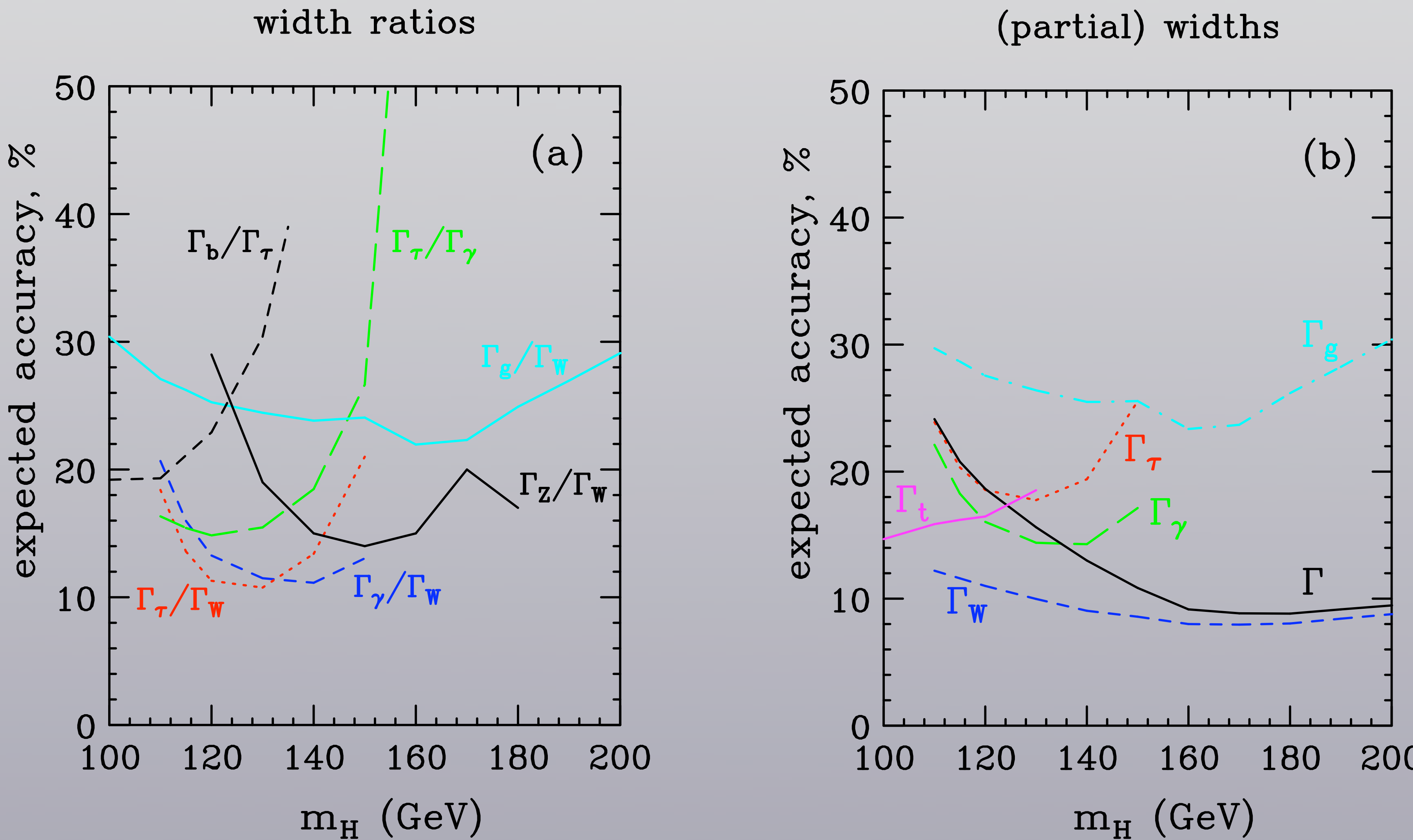
(no VBF)



(qq-> qqh included)

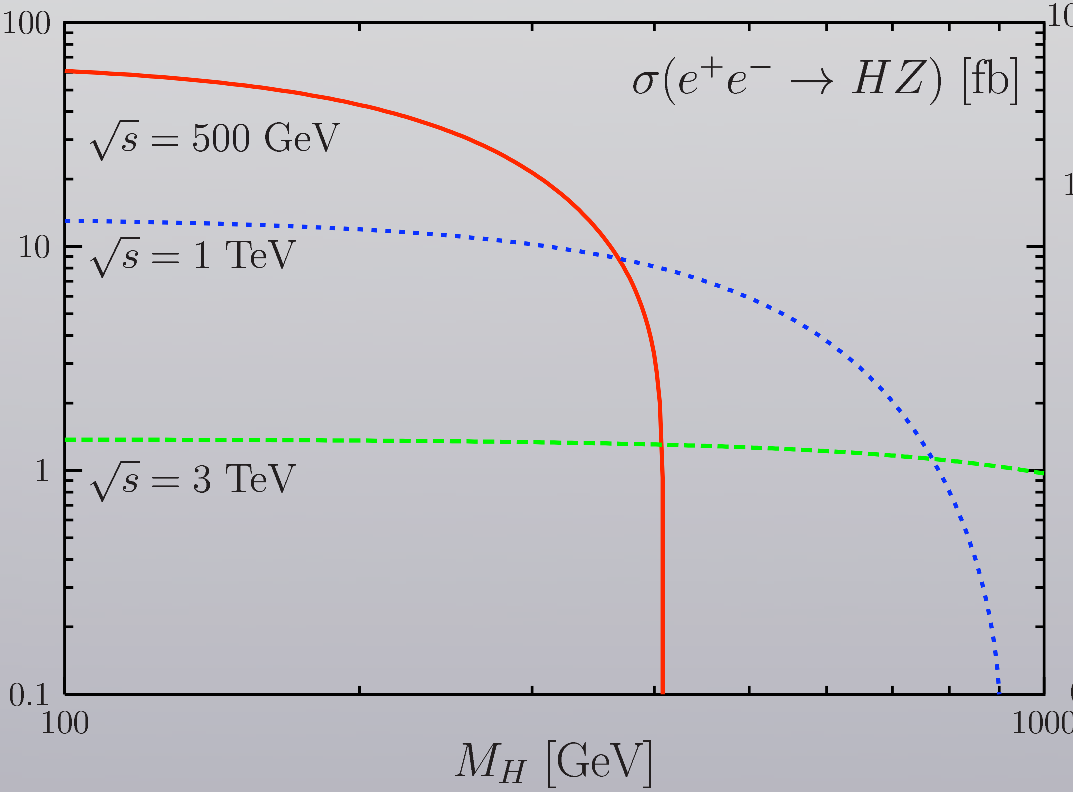
[S. Asai et al. hep-ph/0402254]

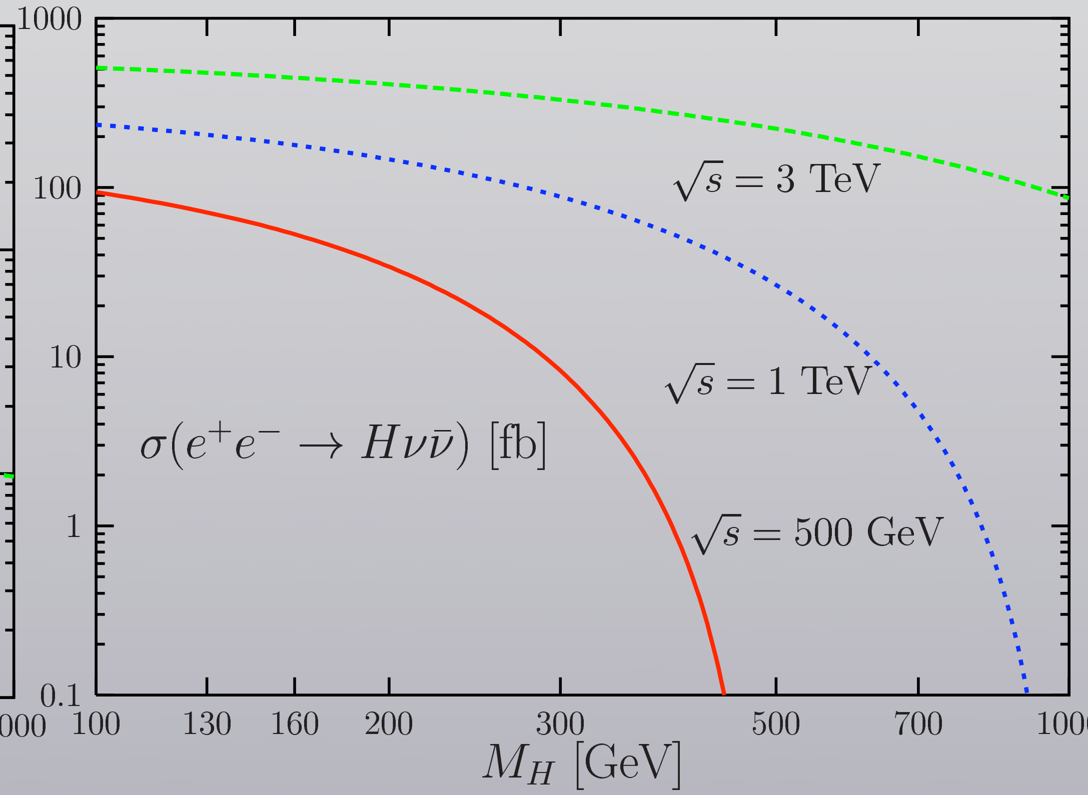
LHC Higgs properties



[M. Duhrssen et al., PRD 70, 113009]

ILC Higgs production

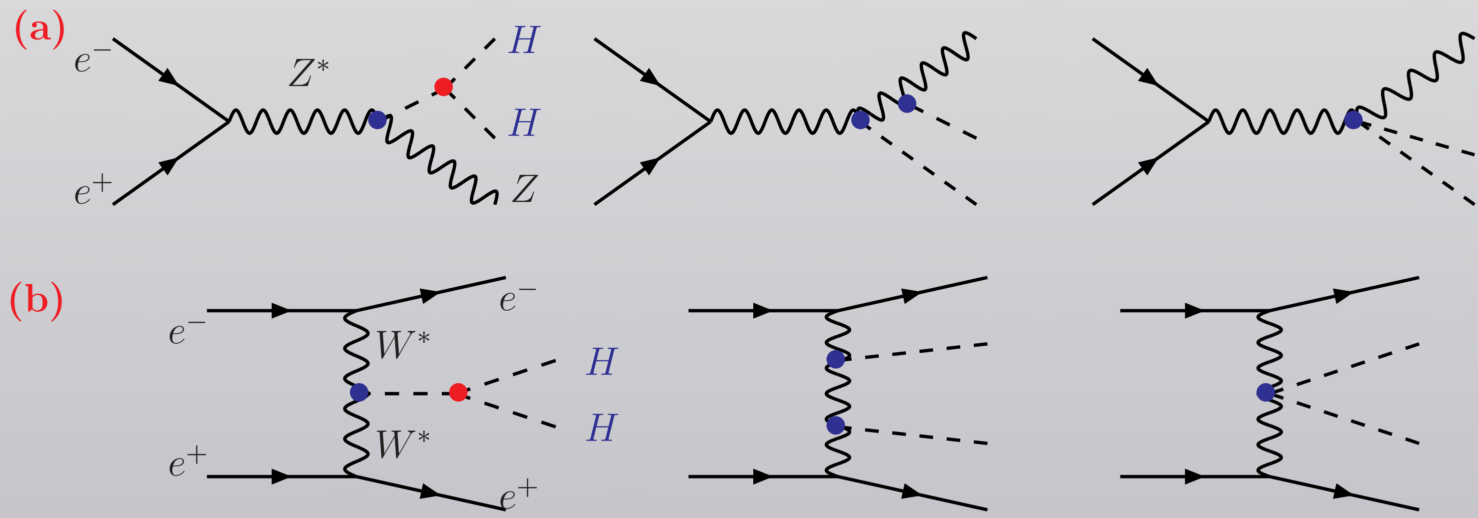




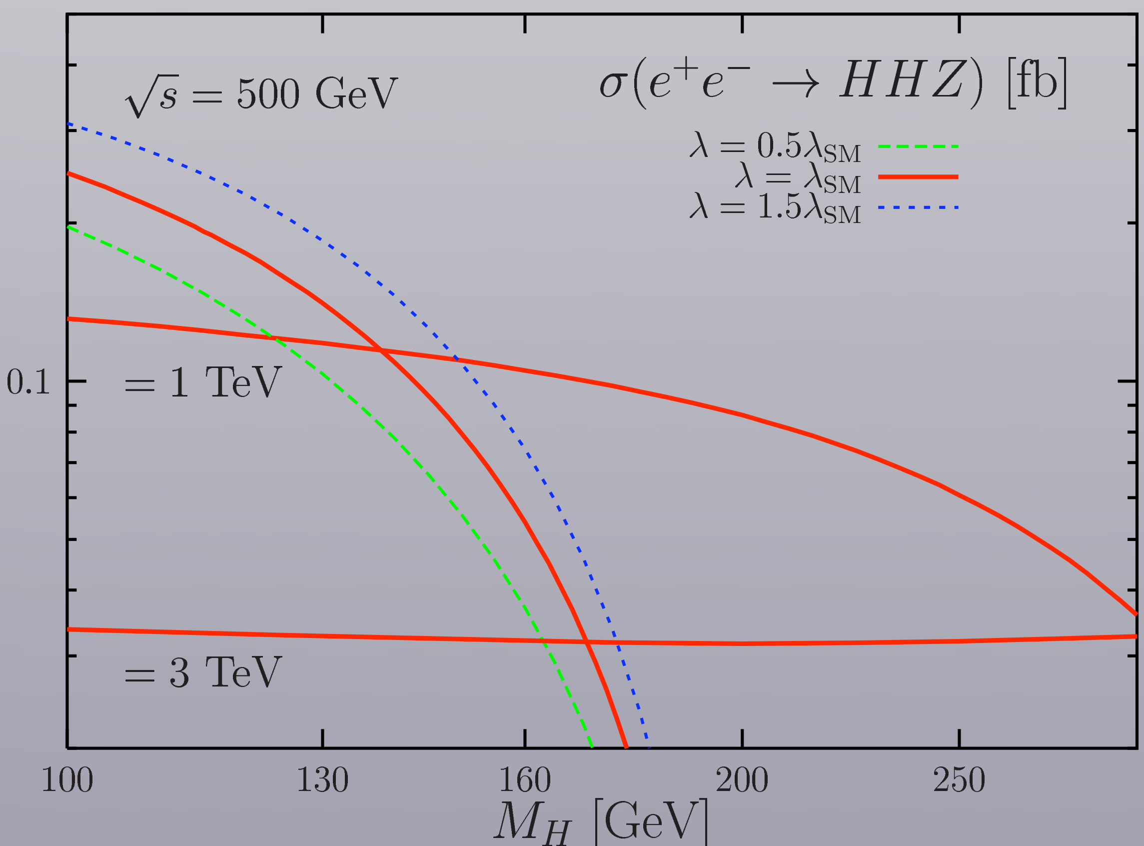
(For the dilaton rescale by v^2/f^2)

[A. Djouadi hep-ph/0503172]

ILC 2 Higgs production



[A. Djouadi hep-ph/0503172]



relative accuracy (500@500)

Quantity	$M_H = 120$ GeV	$M_H = 140$ GeV
ΔM_H	$\pm$ 0.00033	$\pm$ 0.0005
Γ_H	$\pm$ 0.061	$\pm$ 0.045
ΔCP	$\pm$ 0.038	–
λ_{HHH}	$\pm$ 0.22	$\pm$ 0.30
g_{HWW}	$\pm$ 0.012	$\pm$ 0.020
g_{HZZ}	$\pm$ 0.012	$\pm$ 0.013
g_{Htt}	$\pm$ 0.030	$\pm$ 0.061
g_{Hbb}	$\pm$ 0.022	$\pm$ 0.022
g_{Hcc}	$\pm$ 0.037	$\pm$ 0.102
$g_{H\tau\tau}$	$\pm$ 0.033	$\pm$ 0.048

Things to do ...

- Accurate estimates and search strategies at the LHC, what is the best way to determine the decay constant?
- A bound on the cubic coupling, what happens if there are several sources of symmetry breaking?
- What can we learn at the ILC?
- Dilaton mass in nearly conformal gauge theories
- Partial unitarization vs masses of heavy states
- Model-dependent questions