SUSY (&) Higgs Physics

Oliver Brein

(Max-Planck-Institut für Physik, München)

e-mail: obr@mppmu.mpg.de

outline :

- Higgs Bosons, SUSY and Extended Models
- Higgs Production at Future Colliders
- MSSM Higgs Mass Predictions
- Distinguishing Models

• Higgs Bosons, SUSY and Extended Models

– Spontaneous Symmetry Breakdown, Higgs mechanism

Theory: non-abelian gauge symmetry forbids explicit mass terms for gauge bosons.	Experiment: massive vector bosons compatible with non-abelian gauge symmetry have been observed (W, Z)

$\longrightarrow$ contradiction (?) $\longleftarrow$

General solution:
spontaneous symmetry breakdown (SSB), i.e. introduce gauge invariant dynamics, that breaks the gauge symmetry in the ground state of the theory (in the electroweak sector).

Thus, one major task in particle physics is:

to explore and understand the nature of **electroweak symmetry breaking** different models realizing SSB

$\swarrow$ $\searrow$

introduce *weakly* interacting scalar gauge multipletts that acquire a VEV

introduce *strongly* interacting particles that form scalar condensates with a VEV

$\downarrow$ consequences: $\downarrow$

$\rightarrow$ existence of Higgs particle(s)

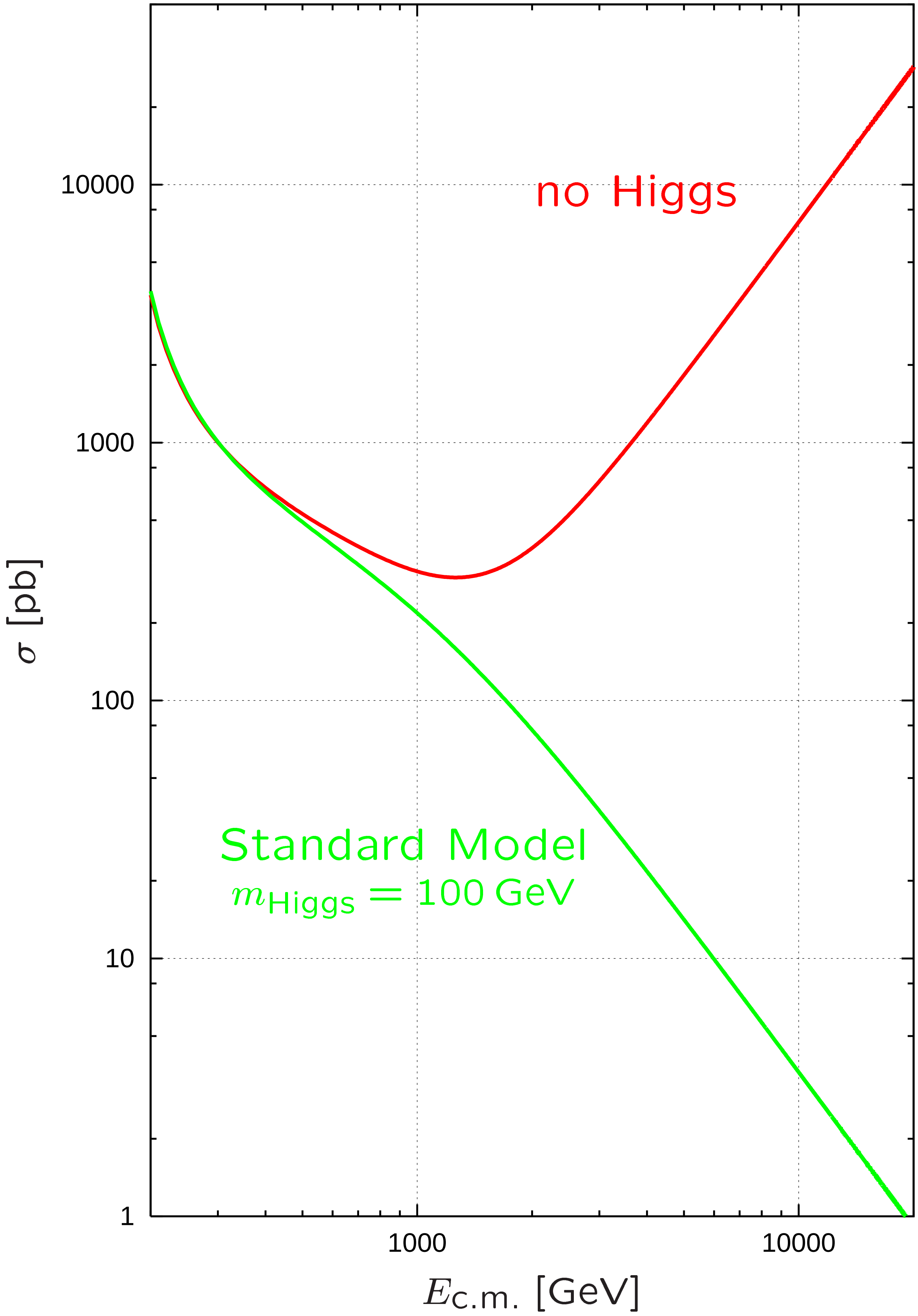
$\rightarrow$ theory may be applicable up to very high energy ($\sim M_{\text{GUT}}$ or M_{Planck}).
If so, then:
Higgs is light, mass $m_H < 1\,\text{TeV}$

$\underbrace{}$
$\boxed{\text{the Higgs mechanism}}$

$\rightarrow$ new effects of strong interaction at $\approx 1\,\text{TeV}$ (e.g. in WW-scattering)

[Higgs Bosons, SUSY and Extended Models, SSB]

$\sigma(WW \to WW)$ at tree-level



– Standard Model and Extensions

SM: matter, gauge bosons
+ 1 Higgs doublet Φ
$\rightarrow$ 1 physical Higgs boson

$\swarrow$ $\searrow$

THDM: SM matter, SM gauge bosons + 2 Higgs doublets Φ_1, Φ_2	MSSM: SM matter, SM gauge bosons + 2 Higgs doublets Φ_1, Φ_2 + Superpartners

$\rightarrow$ 5 physical Higgs bosons: h^0, H^0, A^0, H^+, H^-

So far : – no signal of a Higgs,
– no significant deviation from SM predictions.

Extensions of the SM (Higgs sector) are possible, but they have to agree with present observations, e.g.

- the electroweak rho-parameter
  $\rho_{\text{exp.}} = \frac{m_W}{\cos\theta_W m_Z} \approx 1$ up to a few permille,
- absence of flavour changing neutral currents (FCNC).

– Supersymmetry . . .

. . . is an extension of the Poincaré-symmetry of space-time

. . . leads to a symmetry between Fermions & Bosons

gauge theory with minimal SUSY :

- same # of fermionic & bosonic d. o. f.
  $\rightarrow$ a superpartner of different Spin exists for each particle

- couplings are correlated
  e.g. scalar 4-point int. $\leftrightarrow$ gauge couplings

- superpartners have the same mass.
  $\rightarrow$ SUSY must be broken at the electroweak scale

[Higgs Bosons, SUSY and Extended Models, Supersymmetry]

gauge theory with broken SUSY :

- superpartner masses enter essentially as additional free parameters

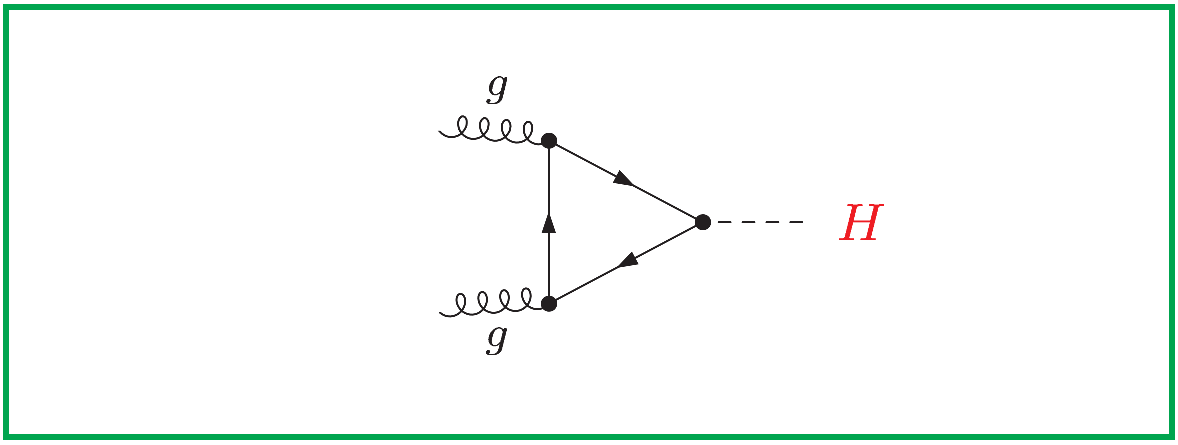
- Higgs boson properties depend on superpartners at the quantum level

• Higgs Production at Future Colliders

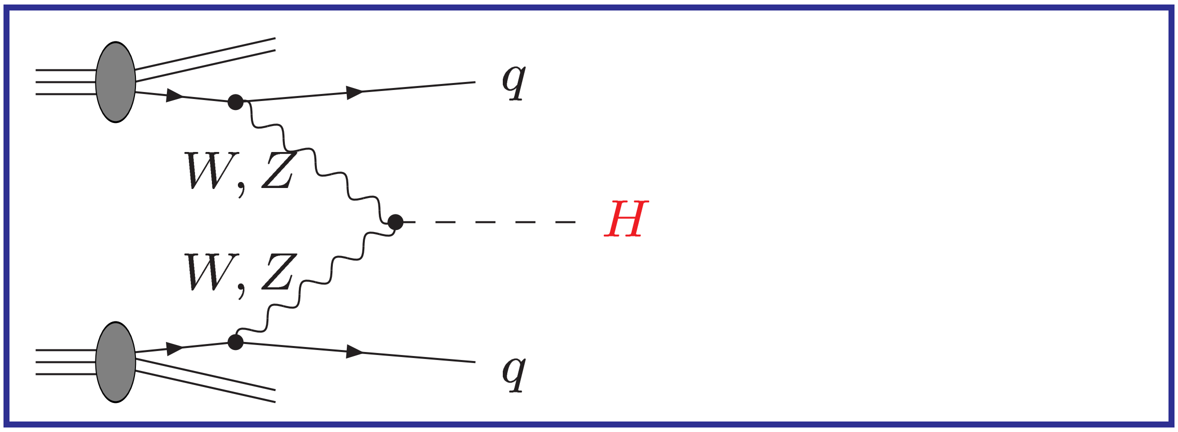
– the lightest Higgs / SM Higgs

Production Processes at the LHC:

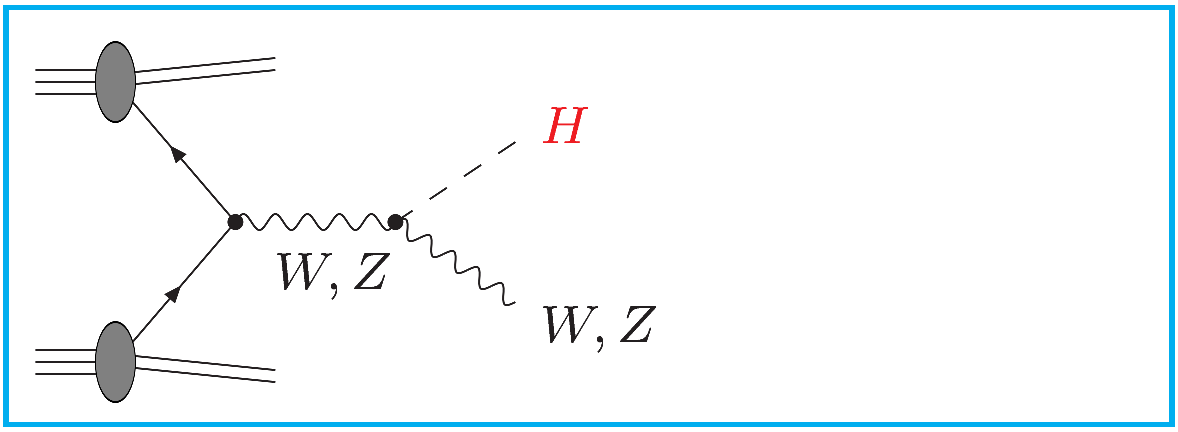
- gluon fusion, $gg \to H$



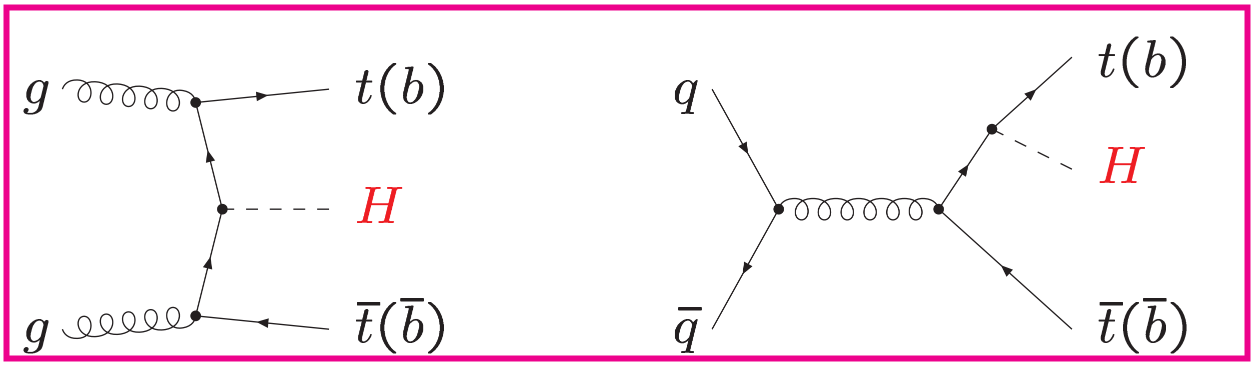
- vector boson fusion, $qq \to qqH$



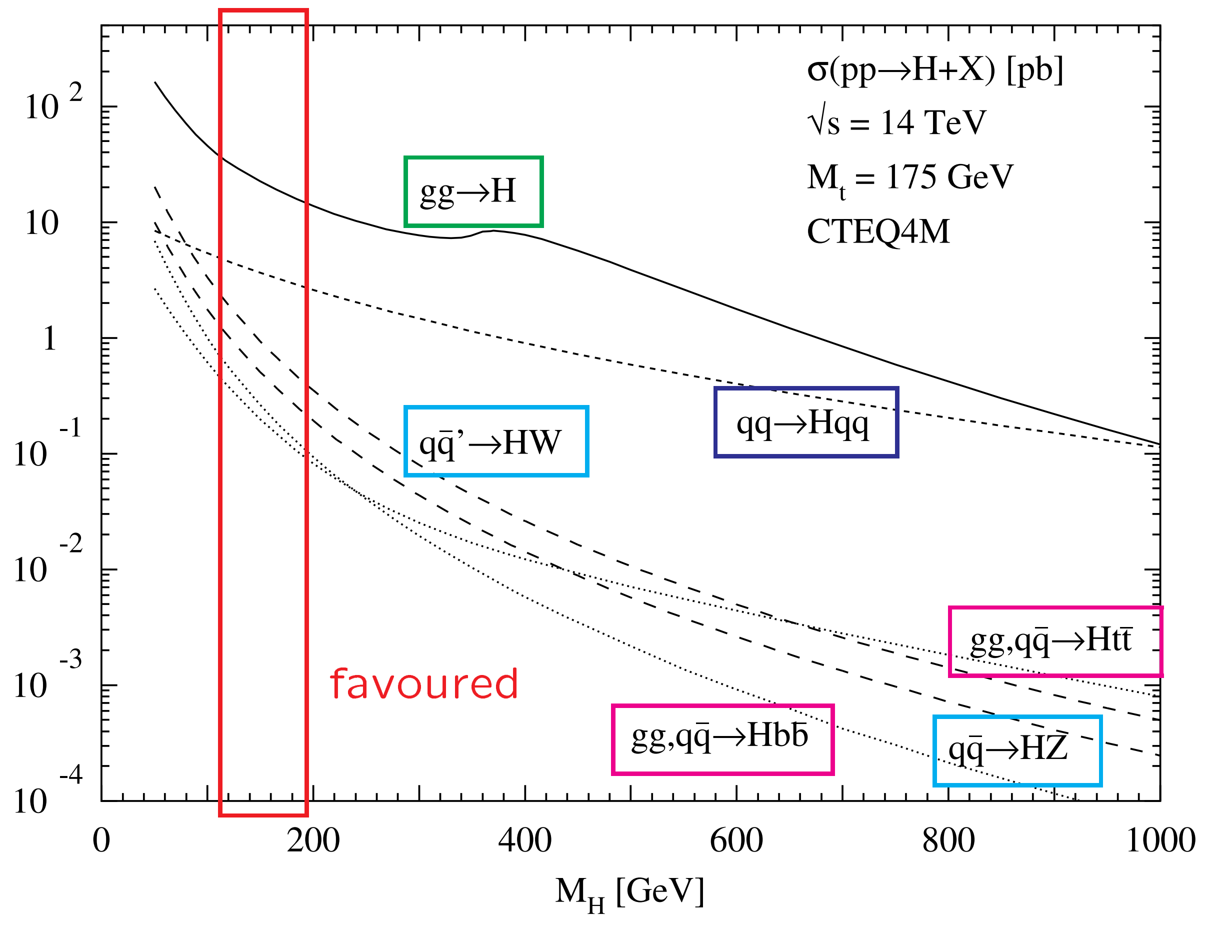
- Higgs strahlung, $q\bar{q}' \to VH$



- $t\bar{t}H$ $(b\bar{b}H)$ production

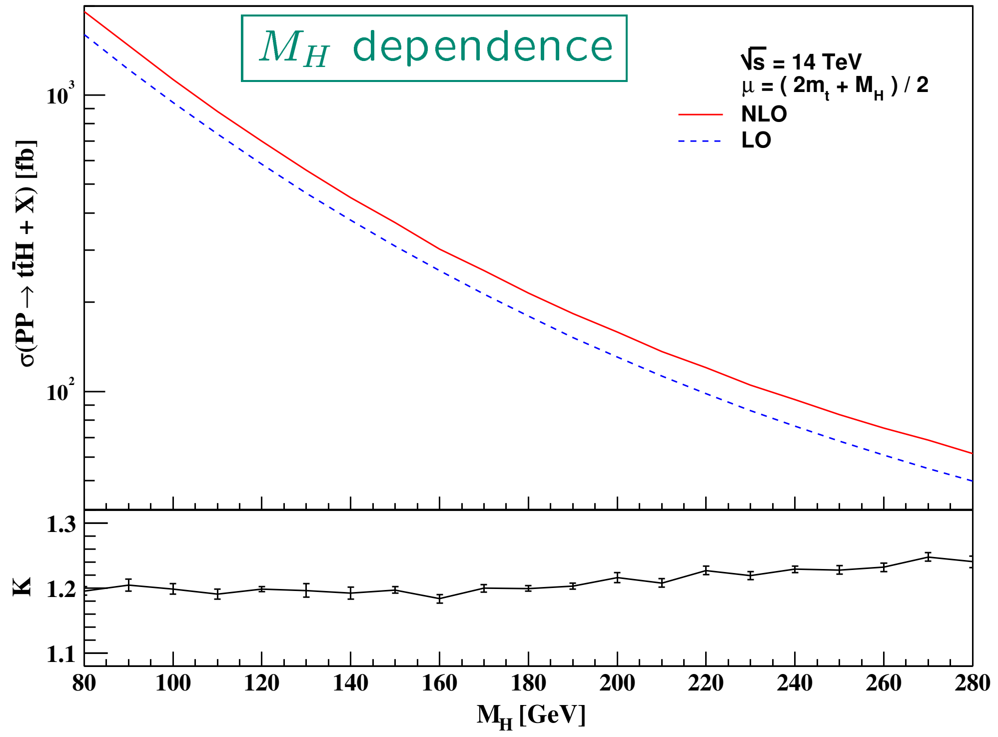


Predictions for SM Higgs Production @ LHC :

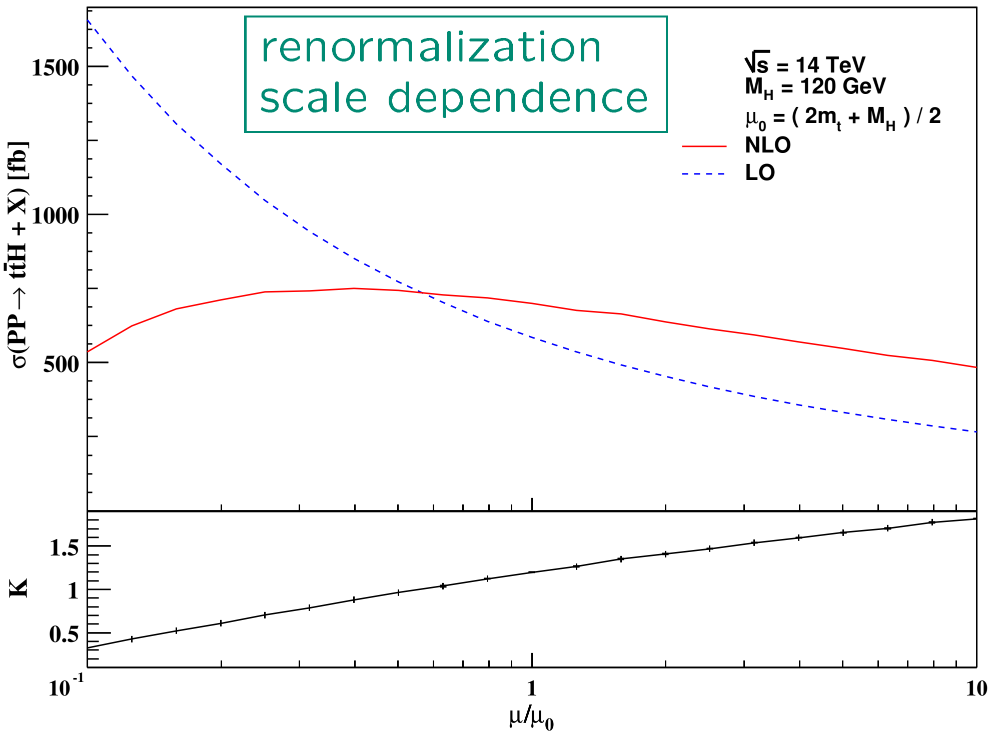


NLO result for the $t\bar{t}H$ cross section

[Beenakker, Dittmaier, Krämer, Plümper, Spira, Zerwas '01]



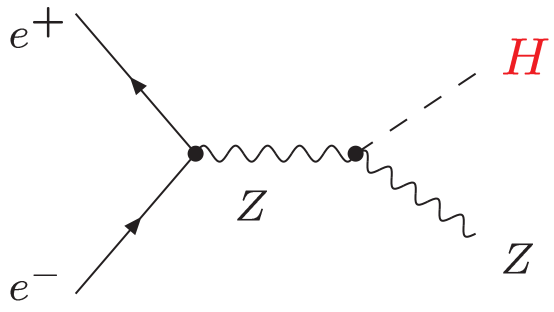
→ cross section ≈ 20% increased



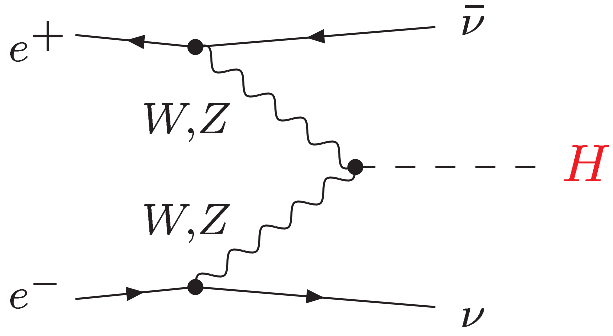
→ stabilisation of prediction in NLO

Production Processes at an e^+e^- Collider:

- Higgs strahlung, $e^+e^- \to ZH$



- vector boson fusion, $e^+e^- \to \nu\bar{\nu}H$



- $t\bar{t}H$ production [Dittmaier et al.]

With increasing c. m. energy the dominant channel shifts from HZ to $H\nu\bar{\nu}$.

The $t\bar{t}H$ production rate is small, but useful for measuring the top-quark Yukawa coupling.

– additional Higgs Bosons

charged Higgs production ...

[Arhrib; OBr, Hahn, Hollik]

(unambigous sign of an extended Higgs sector)

... @ LHC :

$gg \to H^+ \bar{t} b +$ c.c., $g\bar{b} \to H^+ \bar{t} +$ c.c.

$gg/b\bar{b} \to W^\pm H^\mp$

$gg/q\bar{q} \to H^+ H^-$

... @ an e^+e^- collider:

Energy $> 2m_{H^\pm}$: $e^+e^- \to H^+H^-$

Energy $< 2m_{H^\pm}$: $e^+e^- \to \tau^- \bar{\nu}_\tau H^+ +$ c.c.

$e^+e^- \to W^\pm H^\mp$

heavy neutral Higgs production :

[Arhrib; Hahn, Heinemeyer, Weiglein]

CP-even Higgs (H^0) : same processes as for the light neutral Higgs (h^0)

CP-odd Higgs (A^0) ...

... @ LHC :

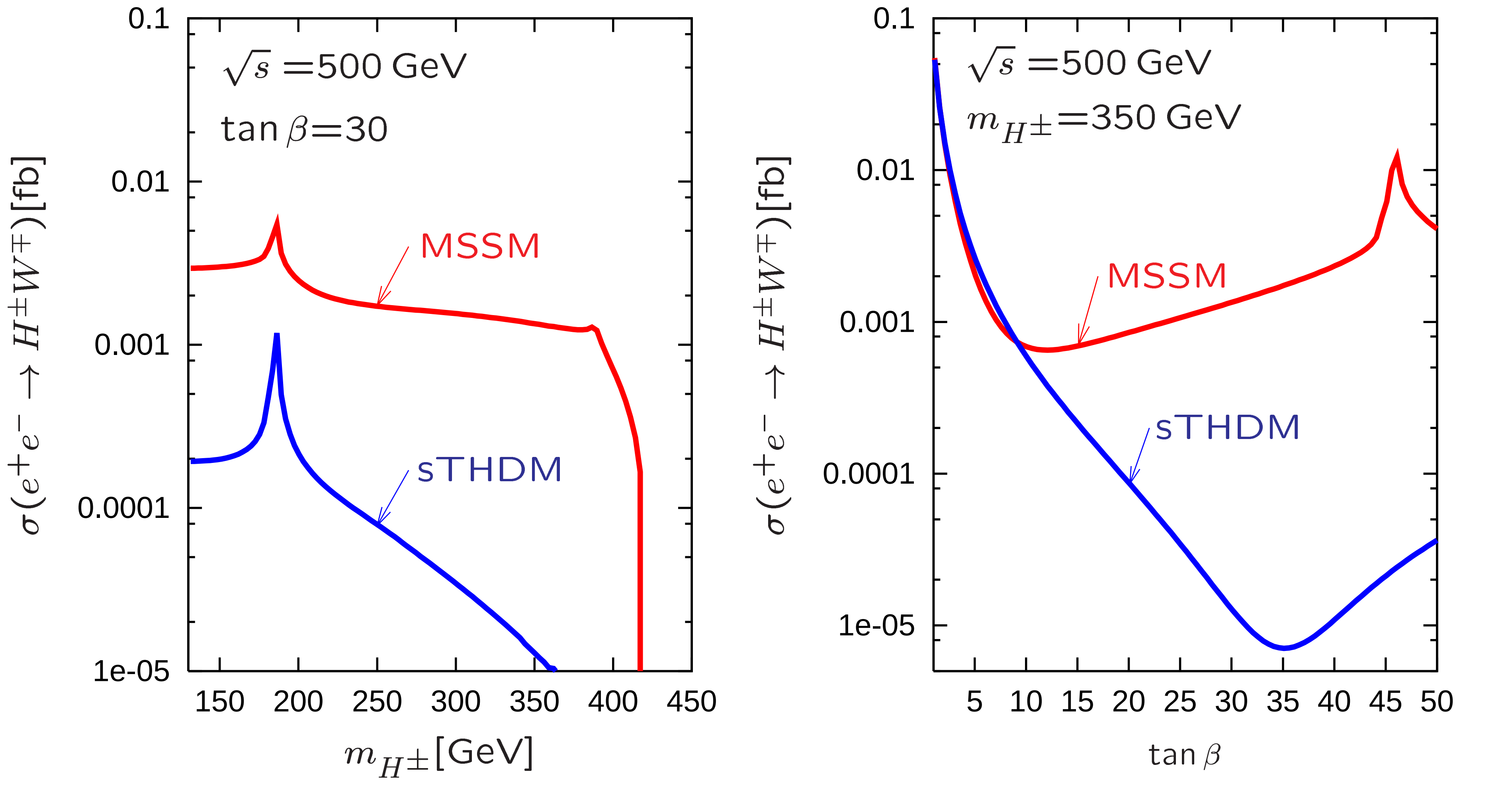
$gg \to A^0$ (gluon fusion)

$gg/q\bar{q} \to b\bar{b}A^0/t\bar{t}A^0$ (via Yukawa interaction)

... @ an e^+e^- collider:

$e^+e^- \to Z^\star \to h^0 A^0 \,/\, H^0 A^0$

$e^+e^- \to H^\pm W^\mp$ [THDM: Arrhib / MSSM: OBr, Hahn, Hollik]



$\to$ Process loop-induced. MSSM and MSSM-like THDM can differ by a factor 10-100.

• MSSM Higgs Mass Predictions

Because of SUSY all scalar 4-point interactions in the MSSM are determined by gauge couplings ($\to$ no free parameters).

Therefore :

- the mass spectrum of the MSSM Higgs sector is determined (at tree-level) by two input parameters (m_{A^0}, $\tan\beta = v_2/v_1$),

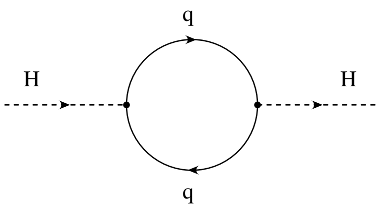
- there is an upper bound on the lightest neutral Higgs mass (m_{h^0}).

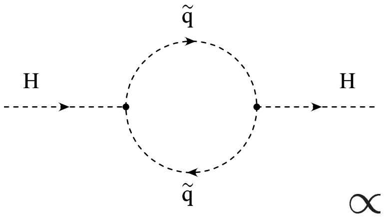
The tree-level prediction of the MSSM is already ruled out by the present LEP data.

But:

- There are large quantum corrections to m_{h^0}

e.g.

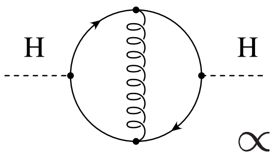




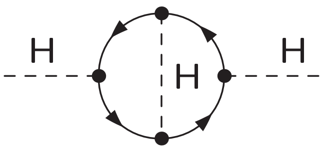
$\propto \alpha_t$

- Even 2-loop corr. to m_{h^0} are significant.

e.g.

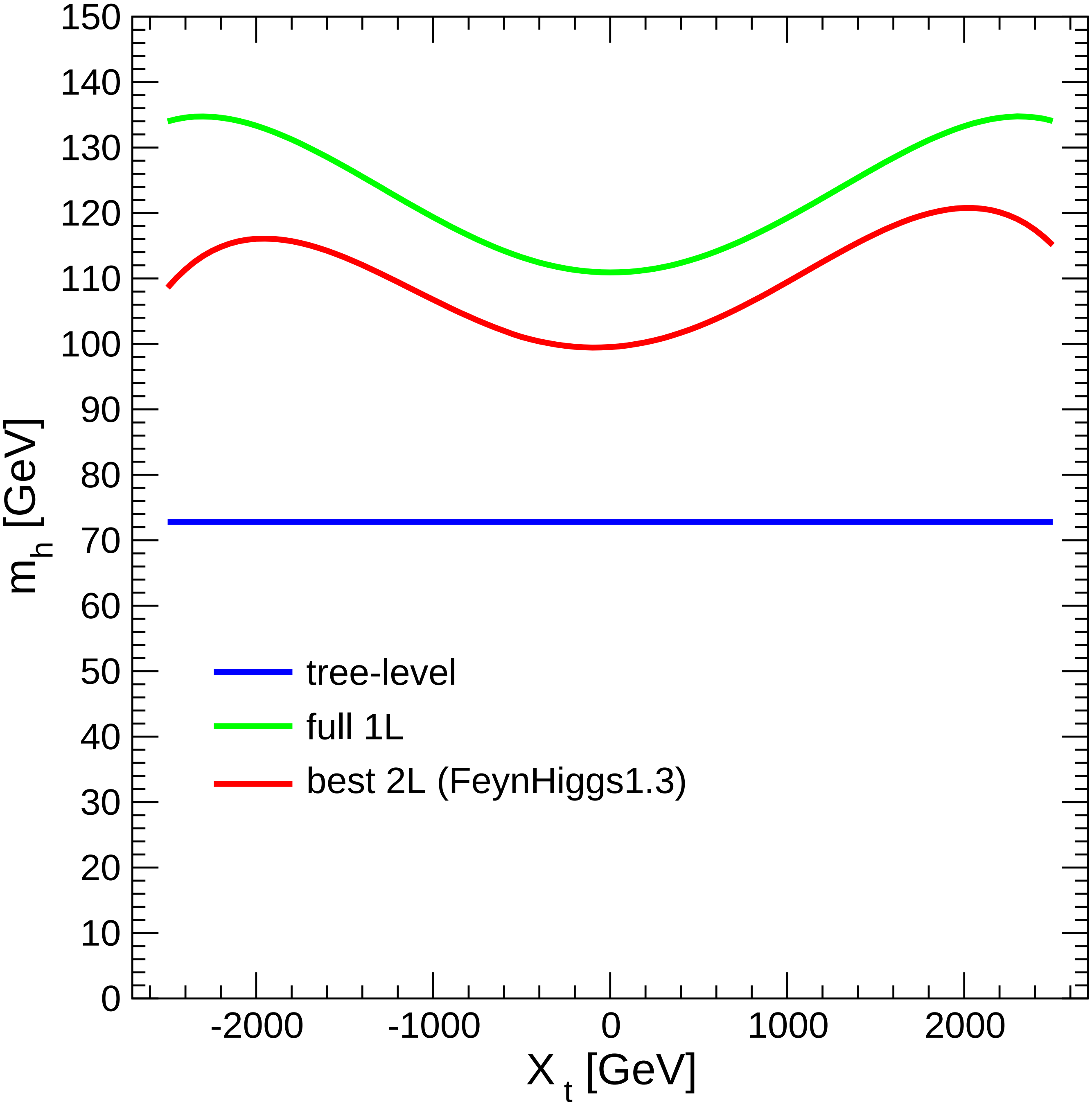


$\propto \alpha_t \alpha_s$



$\propto \alpha_t^2$

m_{h^0} prediction at different levels of accuracy:

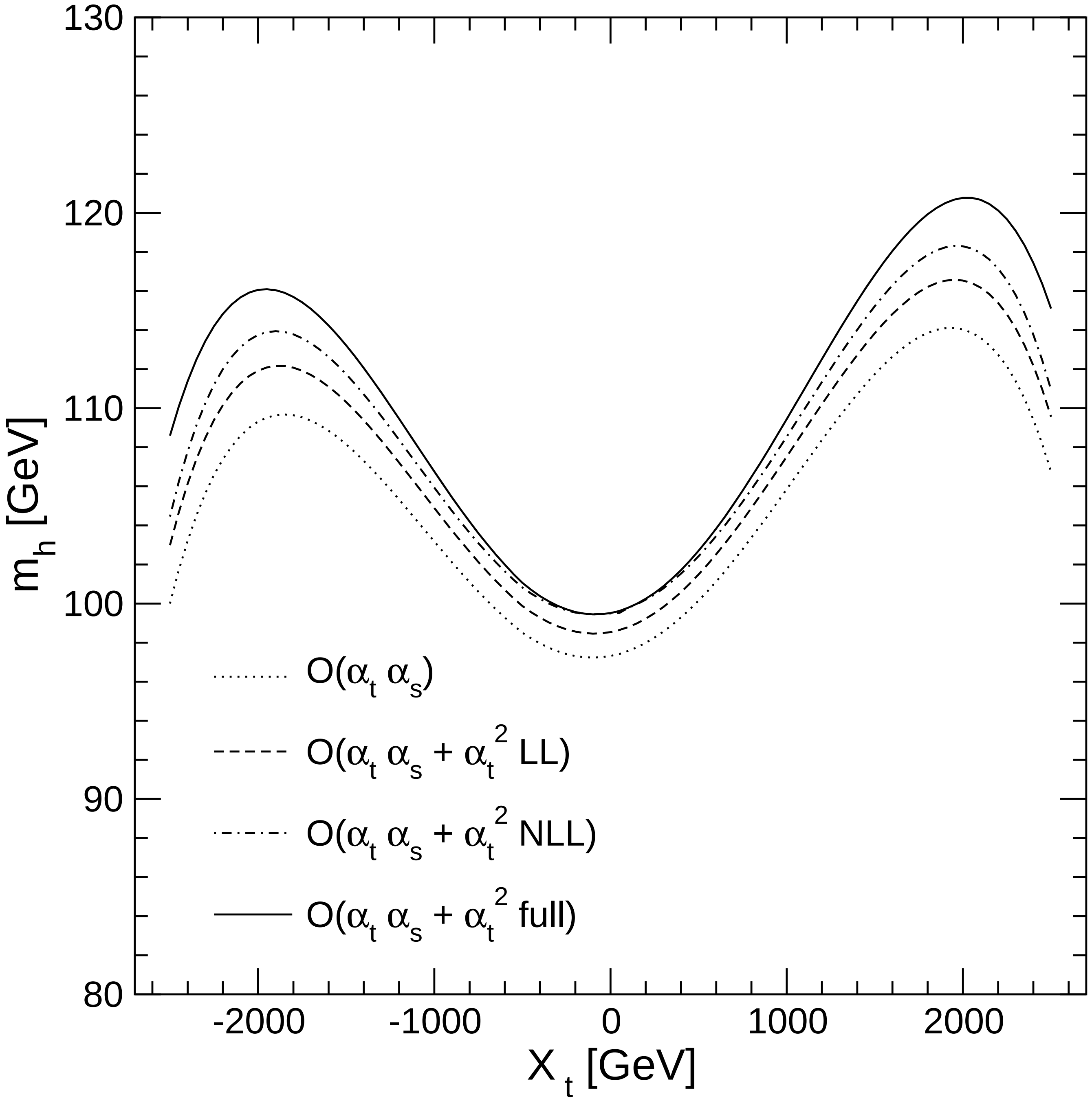


$\tan\beta = 3, \quad M_{\tilde{Q}} = M_A = 1$ TeV, $\quad m_{\tilde{g}} = 800$ GeV

X_t : top-squark mixing parameter

Present status of two-loop contrib. to m_{h^0} :

[Degrassi, Heinemeyer, Hollik, Slavich, Weiglein]



$\tan\beta = 3, \quad M_{\tilde{Q}} = M_A = 1$ TeV, $\quad m_{\tilde{g}} = 800$ GeV

What is the use of a precise prediction for m_{h^0}?

- Precise knowledge of the range of possible Higgs masses in the MSSM.
  $\rightarrow$ MSSM falsified if range excluded.

- Finding a Higgs *in* the range will give strong constraints on the MSSM parameters.

Further work is in progress

[Heinemeyer, Hollik, Rzehak, Slavich, Weiglein]

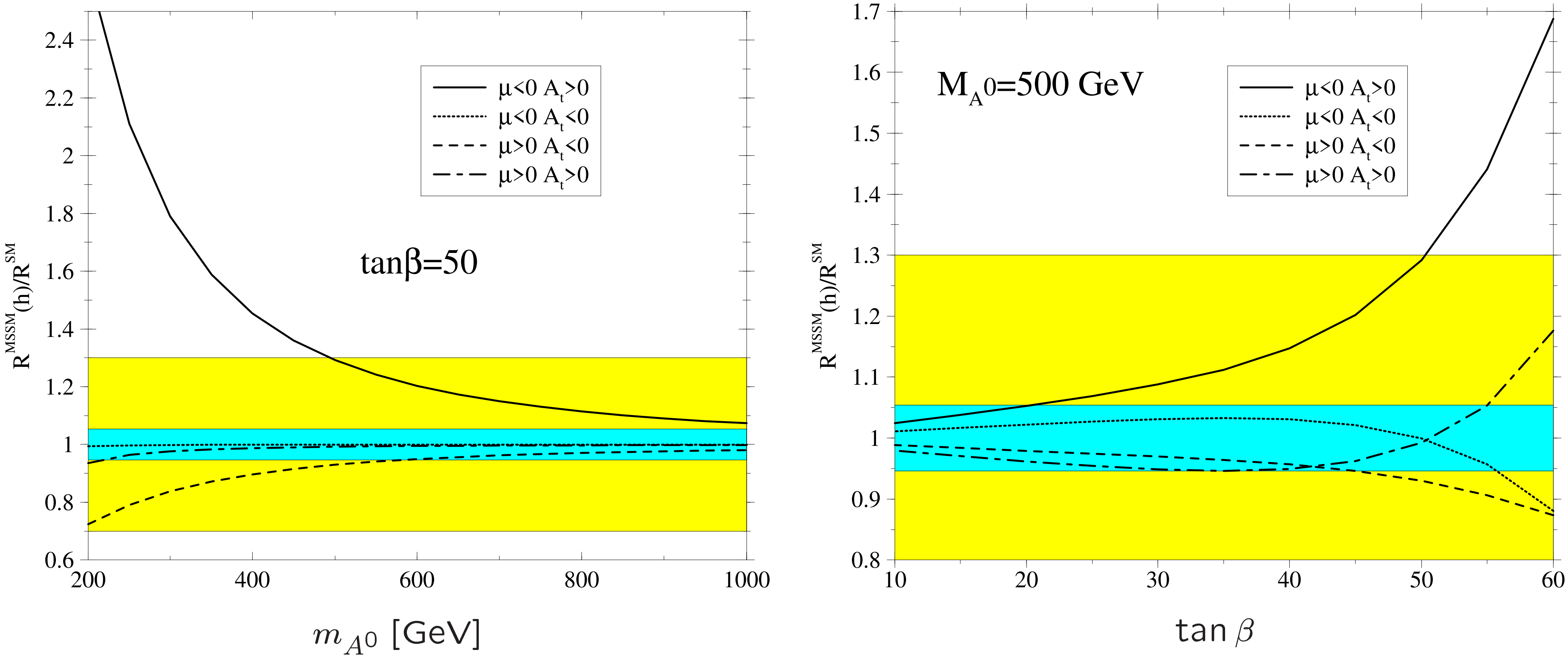
- Distinguishing Models

– Indirect Signs of Extended Models

Problem: Are there observables carrying indirect signs, characteristic for the underlying model of the Higgs sector ?

[Guasch, Hollik, Peñaranda]

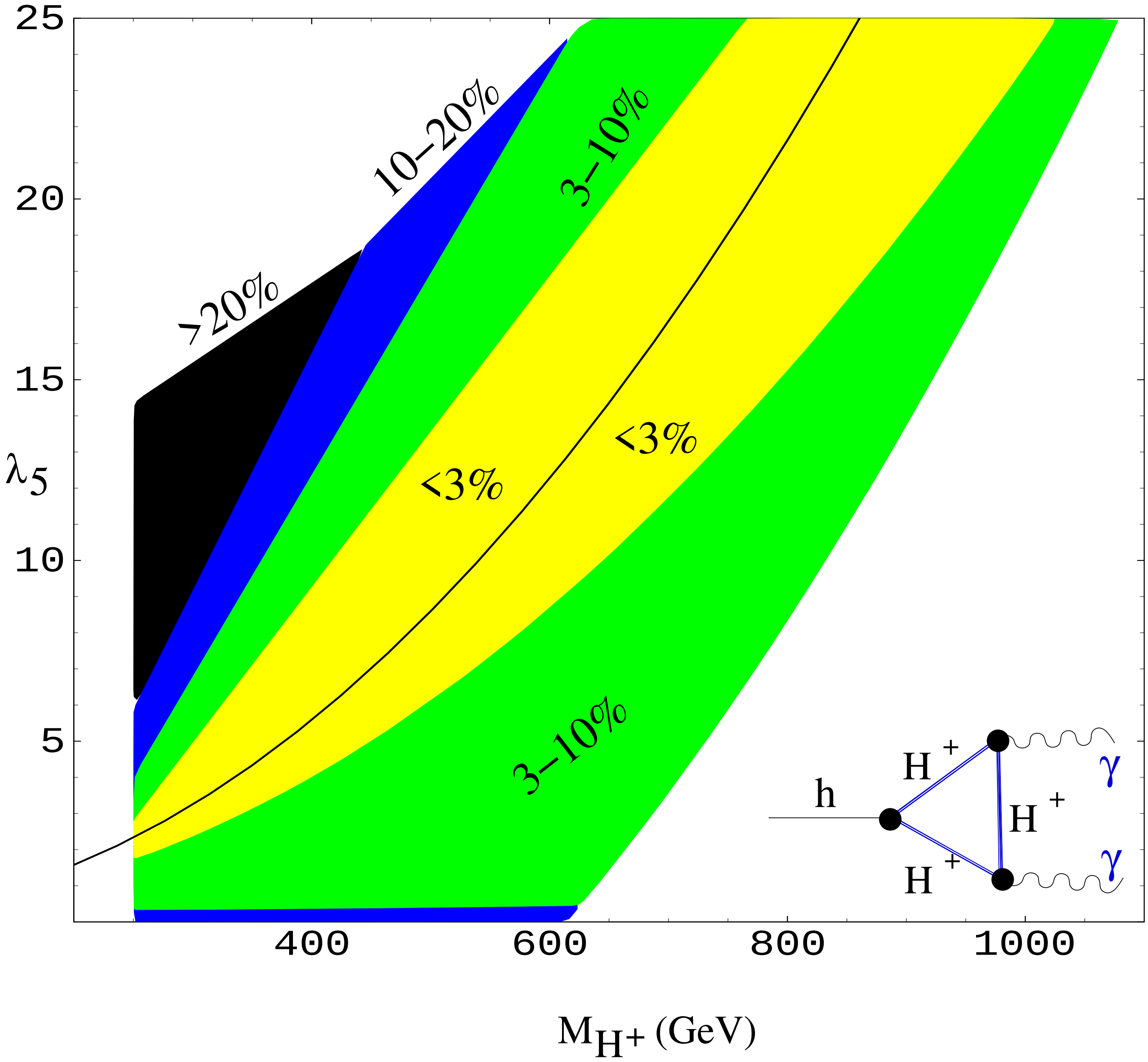
Ratio of $R(h) = BR(h \to b\bar{b})/BR(h \to \tau^+\tau^-)$ in the MSSM versus SM



Yellow band: LHC accuracy (±30%), cyan band: TESLA accuracy (±5.4%).

[Arhrib, Capdequi Peyranère, Hollik, Peñaranda]

$$|R_{\gamma\gamma}-1|=|BR(h_{THDM}\to\gamma\gamma)/BR(H_{SM}\to\gamma\gamma)-1|$$



λ_5 : free parameter in the THDM

black line: hH^+H^- coupling vanishes, THDM resembles SM result.

– Superpartner Processes

[Fritzsche; Jahn]

- one-loop corrections to chargino/neutralino mass spectrum
- radiative corrections for chargino/neutralino production processes
- squark mixing in the MSSM (e.g. top-squark deacy $\tilde{t} \to c\chi^0$)

summary

- The Higgs mechanism is an attractive way to realize electroweak symmetry breaking.

- The main channels to produce the lightest Higgs are gluon fusion @ the LHC, Higgs strahlung and vector boson fusion @ an e^+e^- collider.

- With further effort the mass of the lightest MSSM Higgs boson will become a precision observable.

- Future colliders can reveal a good deal of information about extended models, even if additional Higgs bosons are not accessible.