What Can We Learn from Finding a Charged Higgs ?

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outline :

- Higgs physics, some remarks
  - why a Higgs ?
  - extended models ($\rightarrow$ the charged Higgs)
- finding the charged Higgs
  - charged Higgs search @ LHC/Tevatron
  - charged Higgs search @ e^+e^- colliders
- beyond the finding:
  an example to reveal the underlying model
  - $W^{\pm}H^{\mp}$ production at LHC
  - $W^{\pm}H^{\mp}$ production at e^+e^- colliders

• Higgs physics, some remarks

– why a Higgs ?

$\underbrace{\text{Theory: non-abelian gauge symmetry forbids explicit mass terms for gauge bosons.} \quad \text{Experiment: massive vector bosons compatible with non-abelian gauge symmetry have been observed } (W, Z)}$

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

Solution: introduce gauge invariant dynamics, that breaks the gauge symmetry in the ground state of the theory.

$\downarrow$

$\boxed{\text{spontaneous symmetry breakdown (SSB)}}$

possibilities to realize 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)

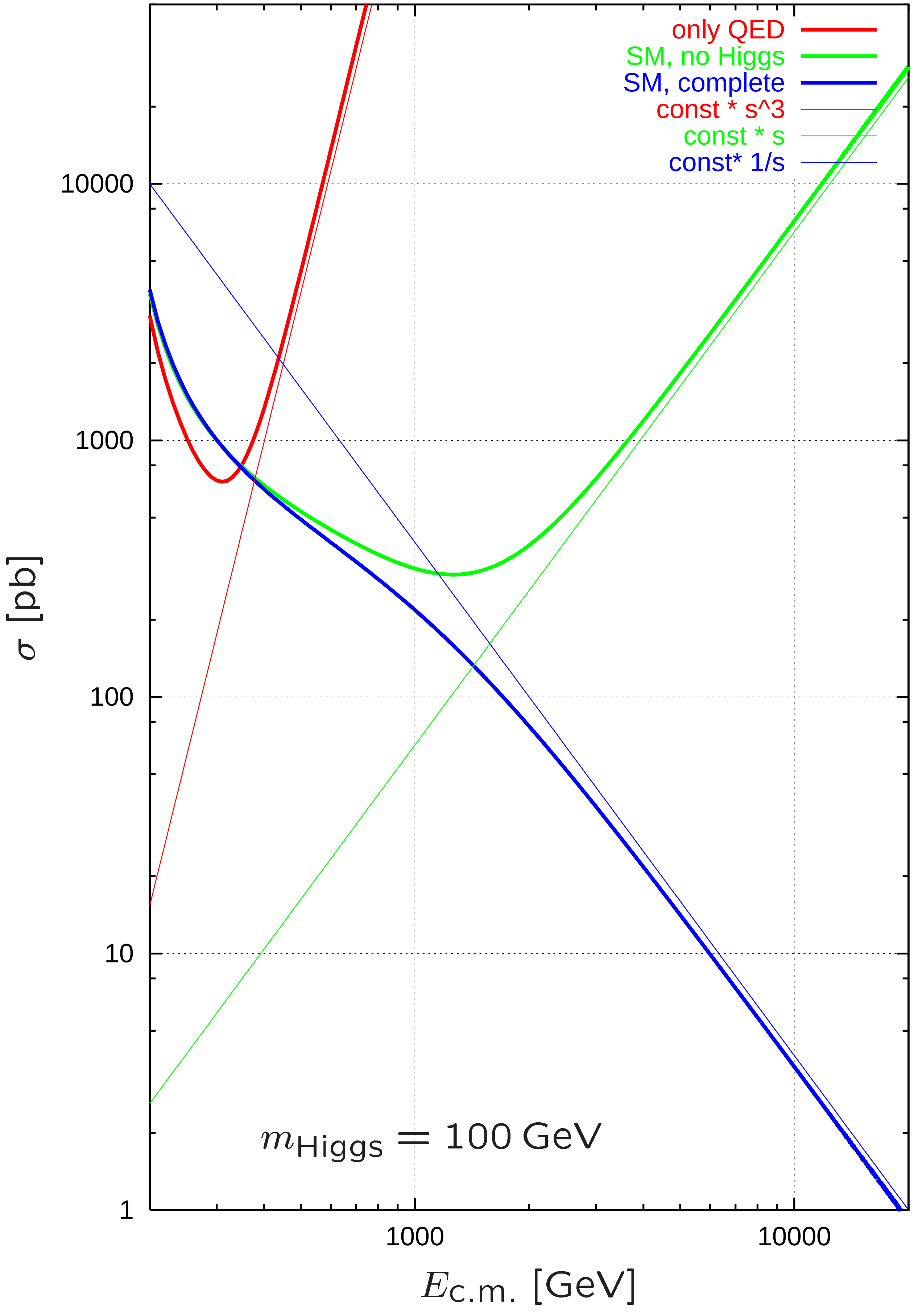
$\rightarrow$ theory may be applicable up to very high energy ($\sim M_{\text{GUT}}$ or M_{Planck}).
If so, then:
Higgs is light, mass $m_H < 1\,\text{TeV}$

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

$\downarrow$

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

$\sigma(WW \to WW)$ in the SM at tree-level



– extended models (the charged Higgs)

Experiment:	Theory:
there is no signal of a Higgs up to now	there are many distinct possibilities to realize the Higgs mechanism

$\downarrow$

$\boxed{\text{this is the main motivation for studying models with extended Higgs sector}}$

important constraints for extended models:

- 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)

simple extensions of the SM:

SM: matter, gauge bosons
+ 1 Higgs doublet Φ

$\swarrow$ $\searrow$

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

Higgs sector in the THDM/MSSM:

- 5 physical Higgs bosons: h^0, H^0, A^0, H^+, H^-
- especially: charged Higgs bosons (H^+, H^-)

Charged Higgs bosons:

cannot appear with *one* Higgs doublet

→ Thus:

$\boxed{\text{the discovery of a charged Higgs is an unambigous sign of an extended Higgs sector}}$

• finding the charged Higgs

– charged Higgs search @ LHC/Tevatron

production processes:

- $gb \to H^+\bar{t} +$ c.c.
  $gg \to H^+\bar{t}b +$ c.c.

$\to$ learn:

- mass ($m_{H^\pm}$)
- tbH-Yukawa coupling

- associated production

$gg \to$ loops $\to W^\pm H^\mp$
$b\bar{b} \to t^\star, \cdots \to W^\pm H^\mp$

$\to$ learn:

- about the virtual particles (e.g. superpartners)
- distinguish MSSM $\leftrightarrow$ THDM

$\to$ underlying model

- pair production

$gg \to$ loops $\to H^+H^-$
$q\bar{q} \to Z^\star, \gamma^\star \to H^+H^-$

$\to$ learn:

- about the virtual particles
- triple Higgs coupling

$\to$ underlying model

– charged Higgs search @ e^+e^- colliders

production processes:

- Energy $> 2m_{H^\pm}$:
  pair production
  $e^+e^-\to Z^\star,\gamma^\star\to H^+H^-$

→ learn:

- mass ($m_{H^\pm}$)

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

→ learn:

- mass ($m_{H^\pm}$)
- $\tau\nu H^\pm$-Yukawa coupling

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

→ learn:

- mass ($m_{H^\pm}$)
- about the virtual particles

→ underlying model

At both kinds of colliders:

$$\boxed{\text{the most important decay for detection is: } H^\pm\to\tau\nu}$$

• beyond the finding: an example to reveal the underlying model

– $W^\pm H^\mp$ production at LHC

(with W. Hollik and S. Kanemura)

partonic processes

(a) $b\bar{b} \to W^\pm H^\mp$, $b\bar{b}$ annihilation

$\to$ mediated at tree-level

$\to$ naive calc. overestimates cross section

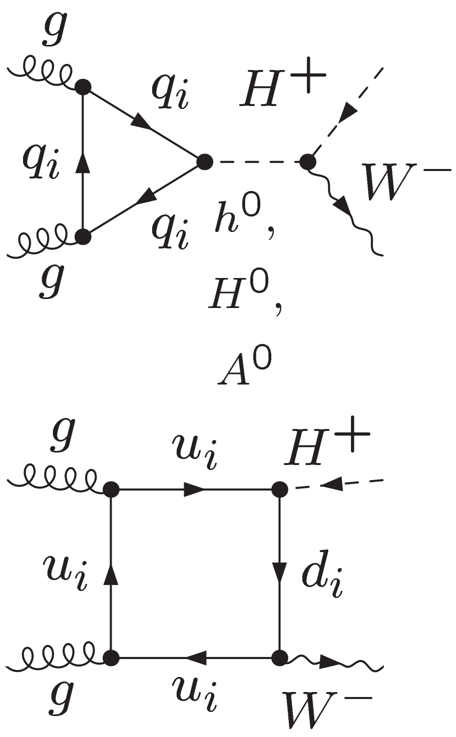
(b) $gg \to W^\pm H^\mp$, gluon fusion

$\to$ loop-induced

$\to$ large # of gg collisions at high Energy pp colliders

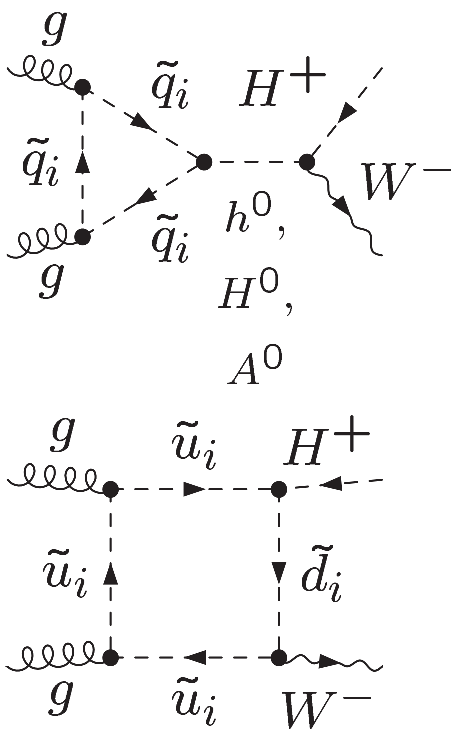
gluon fusion

THDM amplitude



+ more

squark amplitude



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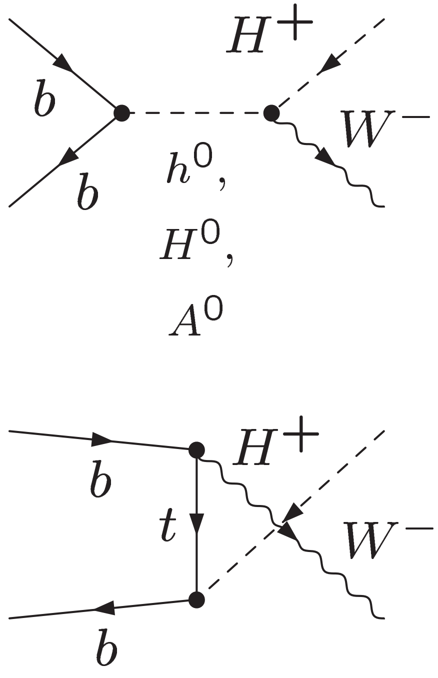
$b\bar{b}$ annihilation



[gg: THDM: Dicus et al. '89; MSSM: Barrientos & Kniehl '99,'00; O.B., Hollik, Kanemura '00
$b\bar{b}$: MSSM: QCD corr. Hollik & Zhu '01]

[beyond the finding, . . . , $W^{\pm}H^{\mp}$ production at LHC]

MSSM results

features:

$b\bar{b}$ annihilation :

→ rather insensitive to SUSY-Spectrum

gluon fusion :

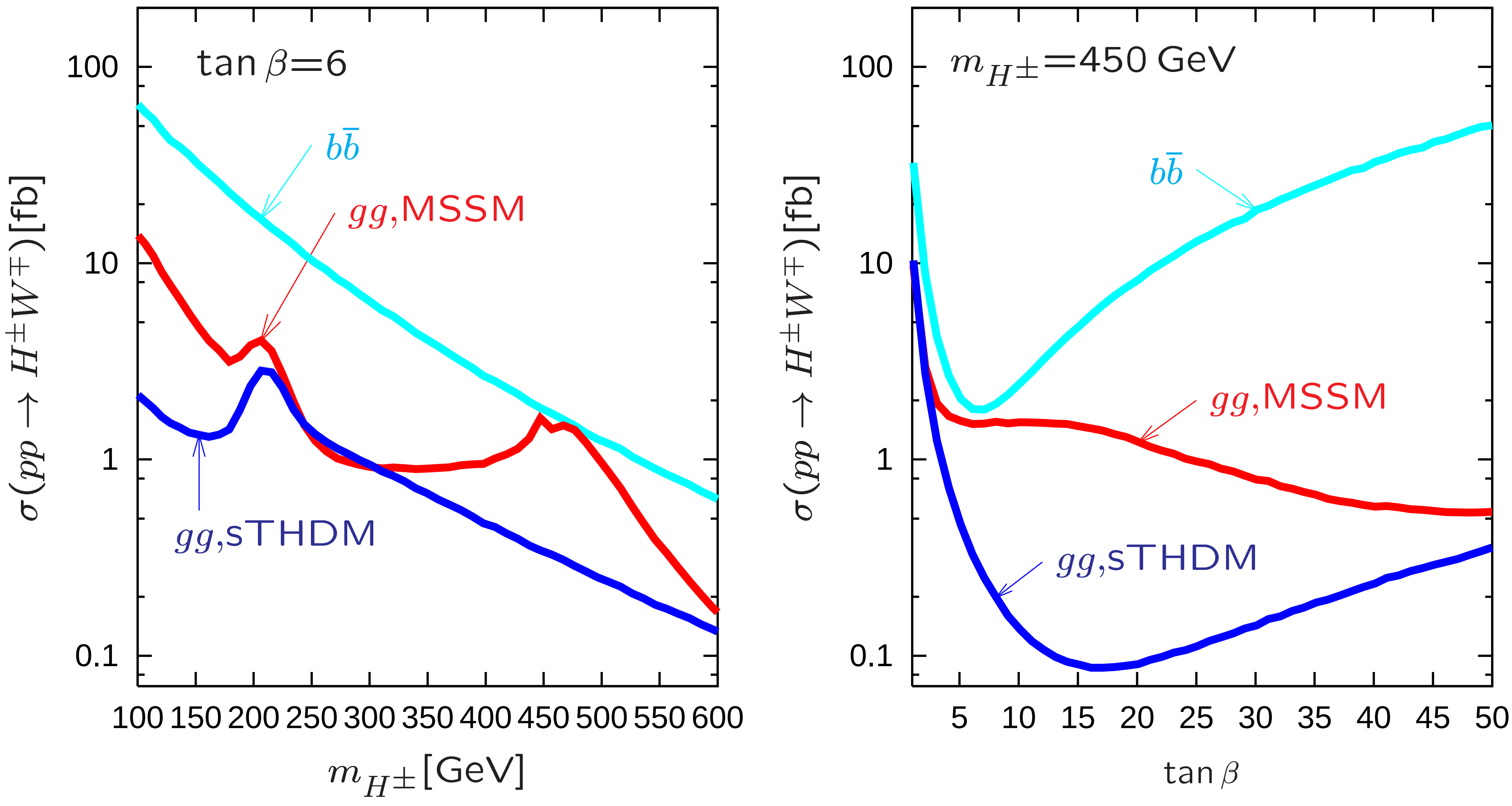
→ sensitive to virtual SUSY-particles

→ large destructive interference between quark loops of box and triangle type.

→ squark contribution can get large due to threshold effects in box loops

both processes:

→ sensitive to the neutral Higgs sector


$\tan\beta$=6
$b\bar{b}$
gg,MSSM
gg,sTHDM
$\sigma(pp \to H^{\pm}W^{\mp})$[fb]
100
10
1
0.1
100 150 200 250 300 350 400 450 500 550 600
$m_{H^{\pm}}$[GeV]
$m_{H^{\pm}}$=450 GeV
$b\bar{b}$
gg,MSSM
gg,sTHDM
$\sigma(pp \to H^{\pm}W^{\mp})$[fb]
100
10
1
0.1
5 10 15 20 25 30 35 40 45 50
$\tan\beta$

THDM results

Note !

In the MSSM the mass relations among the Higgs bosons for large $m_{H^\pm}$ lead to:

$$m_{h^0} = \mathcal{O}(100\mathrm{GeV}),\ m_{H^0} \approx m_{A^0} \approx m_{H^\pm}\ .$$

Thus, in the MSSM:

→ contributions of neutral Higgs s-channel exchange cannot decouple from the process

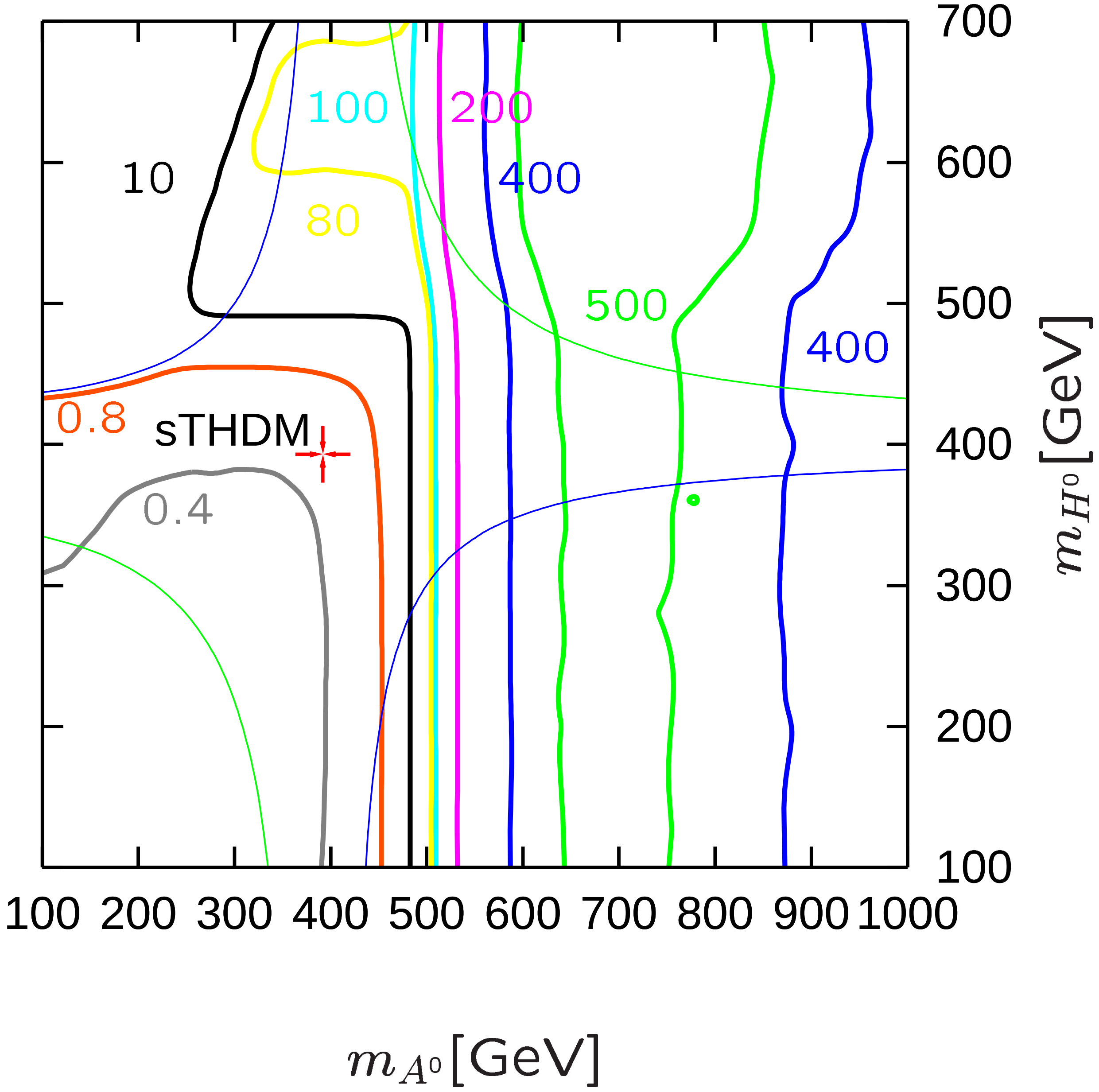
→ no resonant s-channel Higgs exchange possible ($m_{H^\pm} + m_W > m_{h^0,H^0,A^0}$)

→ negative interference between box- and triangle-type quark loops unavoidable

But this is not true in the THDM !

→ cross section in the THDM can be much larger than in the MSSM

$\sigma(pp \to W^{\pm}H^{\mp})$ [fb] in the THDM



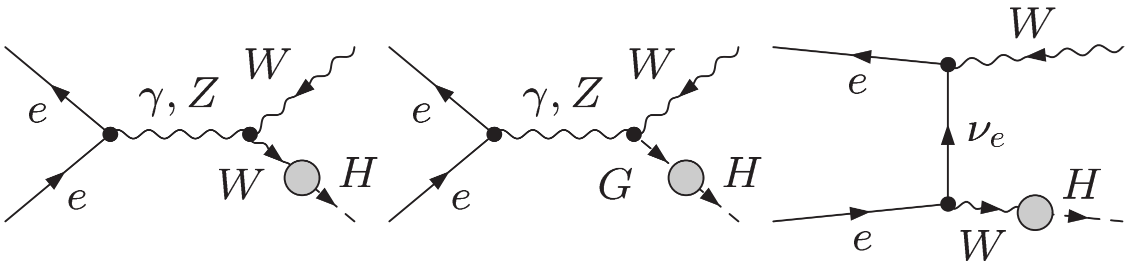
$(m_{H^{\pm}} = 400\,\text{GeV},\ \tan\beta = 6)$

– $W^{\pm}H^{\mp}$ production at $e^{+}e^{-}$ colliders

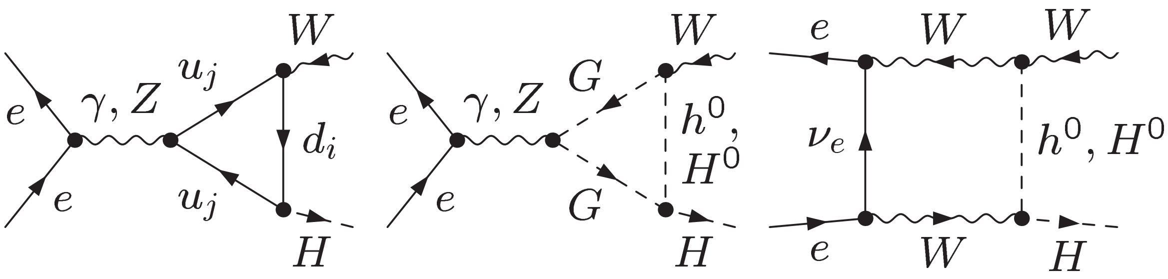
(with W. Hollik and T. Hahn)

amplitude

self energies

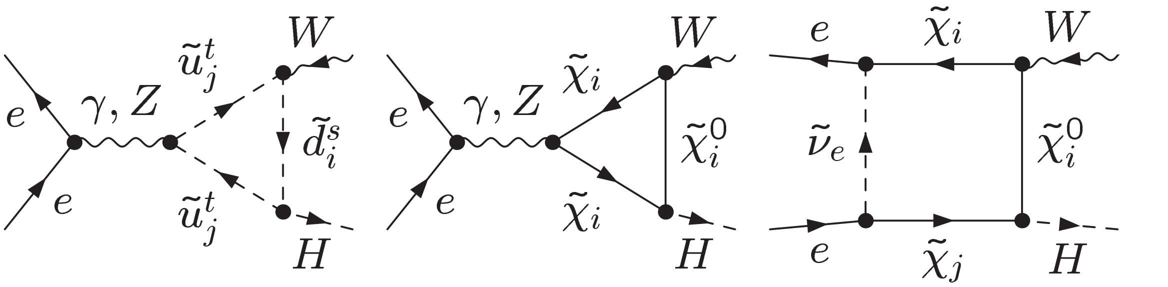


vertices & boxes, THDM like contributions



+ more

vertices & boxes, SUSY contributions



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[THDM: Zhu '99; Arhrib et al. '99; Kanemura '99

MSSM: Logan & Su '02; O.B., Hollik, Hahn '02]

MSSM results

features:

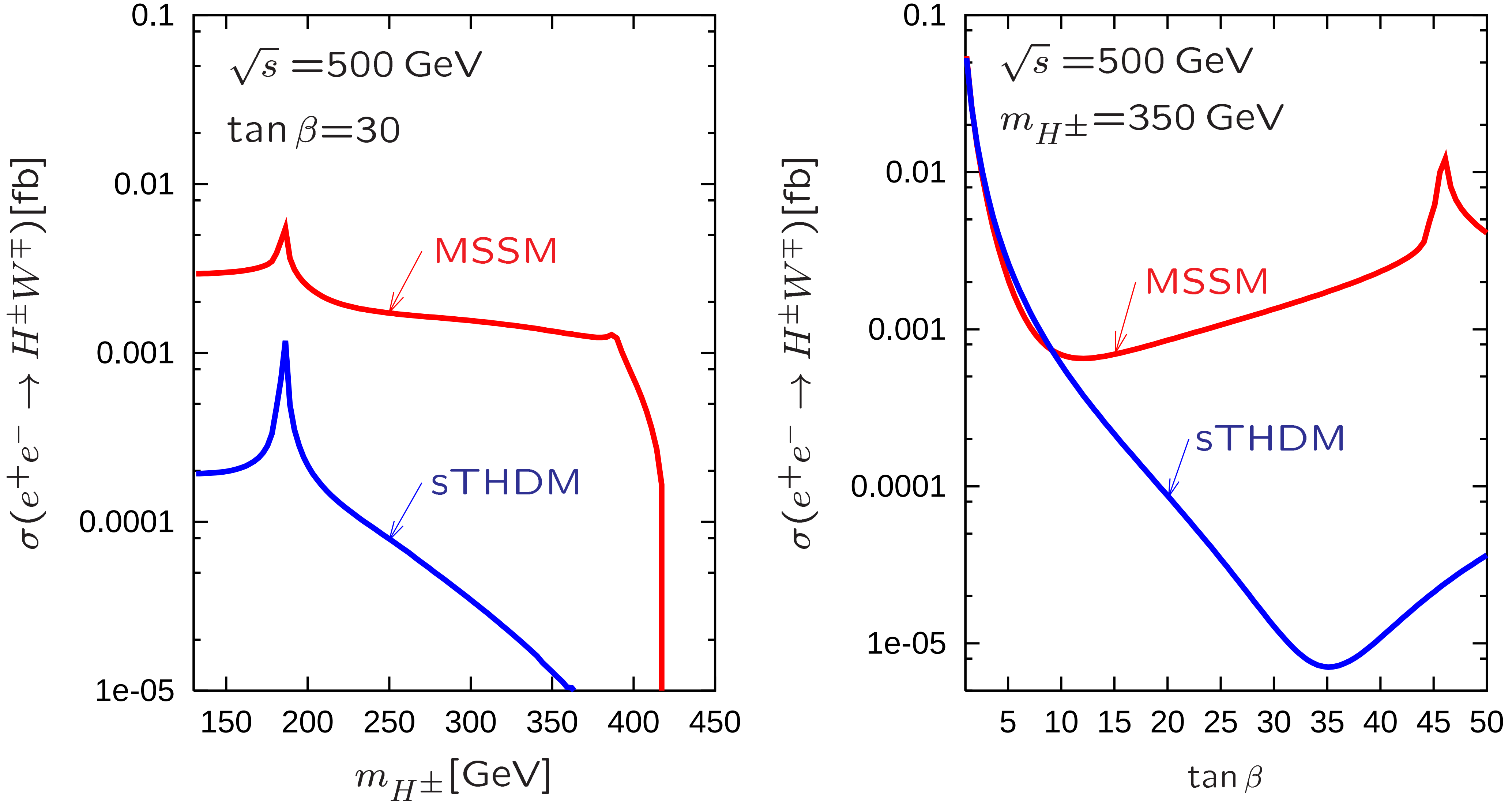
$\rightarrow$ vertex diagramms give main contribution to cross section

$\rightarrow$ squark loops can enhance the cross section of the MSSM wrt the MSSM-like THDM by a factor 10-100 (large $\tan\beta$ (>20))

$\rightarrow$ optimal polarization of e^{-} and e^{+} can increase the cross section by a factor 4

$\rightarrow$ large corrections by neutralino/chargino loops are also possible

[beyond the finding, . . . , $W^{\pm}H^{\mp}$ production at e^+e^- colliders]



summary

- A sensible description of massive vector bosons (like W, Z) requires spontaneous breakdown of gauge symmetries.

  The Higgs mechanism is a way to realize that, leading to the predicition of fundamental scalar particles (Higgs bosons).

- Theories with extended Higgs sectors (e.g. THDM, MSSM) predict several Higgs bosons (esp. charged Higgs bosons, $H^{\pm}$).

  The discovery of $H^{\pm}$ would be an unambigous sign of an extended Higgs sector.

- The rate of THDM/MSSM $H^{\pm}$ production at the LHC and $e^{+}e^{-}$ colliders is enough to find it in a wide range of parameters with the $\tau\nu$ decay signature.

- Once the $H^{\pm}$ is found, the exclusive study of loop-induced processes, like the associated $W^{\pm}H^{\mp}$ production, will reveal more information about the underlying model.