Susy (&) Higgs Physics

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outline :

SUSY Part

- Supersymmetry
  - General remarks
  - The minimal supersymmetric standard model (MSSM)
- Deep inelastic νN scattering at NuTeV
  - The NuTeV result and possible explanations
  - MSSM radiative corrections to νN DIS

Higgs Part

- Higgs bosons, SUSY and extended Models
  - Spontaneous symmetry breakdown, Higgs mechanism
  - Standard Model and extensions
- Higgs production at future hadron colliders
  - How to produce a Higgs boson ?
  - Neutral Higgs production overview
- $H^{\pm}W^{\mp}$ production @ LHC: MSSM vs. THDM
  - Charged Higgs search at LHC/Tevatron
  - MSSM/THDM $H^{\pm}W^{\mp}$ production

SUSY Part

• Supersymmetry

– General remarks

Supersymmetry ...

... is *the* 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.
  $\longrightarrow$ a superpartner of different Spin exists for each particle

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

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

gauge theory with broken SUSY :

- superpartner masses enter as additional free parameters (essentially)

– The minimal supersymmetric standard model (MSSM)

gauge group : $SU(3)_{\text{colour}} \times SU(2)_{\text{isospin}} \times U(1)_{\text{hypercharge}}$

particle content :

regular particle		spin	superpartner		spin
fermions	quarks u, d, s, c, b, t leptons $e, \nu_e, \mu, \nu_\mu, \tau, \nu_\tau$	$\frac{1}{2}$	sfermions	squarks $\tilde{u}, \tilde{d}, \tilde{s}, \tilde{c}, \tilde{b}, \tilde{t}$ sleptons $\tilde{e}, \tilde{\nu}_e, \tilde{\mu}, \tilde{\nu}_\mu, \tilde{\tau}, \tilde{\nu}_\tau$	0
gauge bosons	$G, W^\pm, Z, \gamma$	1	gauginos	$\tilde{G}, \tilde{W}^\pm, \tilde{Z}, \tilde{\gamma}$	$\frac{1}{2}$
Higgs bosons	H_1, H_2	0	Higgsinos	$\tilde{H}_1, \tilde{H}_2$	$\frac{1}{2}$

$\tilde{W}^\pm, \tilde{Z}, \tilde{\gamma}$ and $\tilde{H}_1, \tilde{H}_2$ mix to charginos $\chi_1^\pm, \chi_2^\pm$ and neutralinos $\chi_1^0, \ldots, \chi_4^0$

R-parity : discrete, multiplicative quantum number

$$R(\text{regular particles}) = +1$$
$$R(\text{superpartners}) = -1$$

$\rightarrow$ designed to avoid large Flavour Canging Neutral Currents (FCNC)

consequences of R-parity conservation:

- all interactions involve an *even* number of superpartners
  $\rightarrow$ superpartners can only be pair-produced

- the lightest superpartner (LSP) is stable
  $\rightarrow$ the LSP is a candidate for dark matter

MSSM Parameters (adding to the SM Parameters)

particles		parameters
gauginos/higgsinos $(\chi_i^{\pm}, \chi_i^0, \tilde{G})$	:	mass parameters $M_1, M_2, M_{\text{gluino}}, \mu$
sfermions $(\tilde{f})$	:	mass parameters $M_{\text{Sf.}}, A_f$
Higgs sector (H_1, H_2)	:	$m_{A^0}, \tan\beta = v_2/v_1$

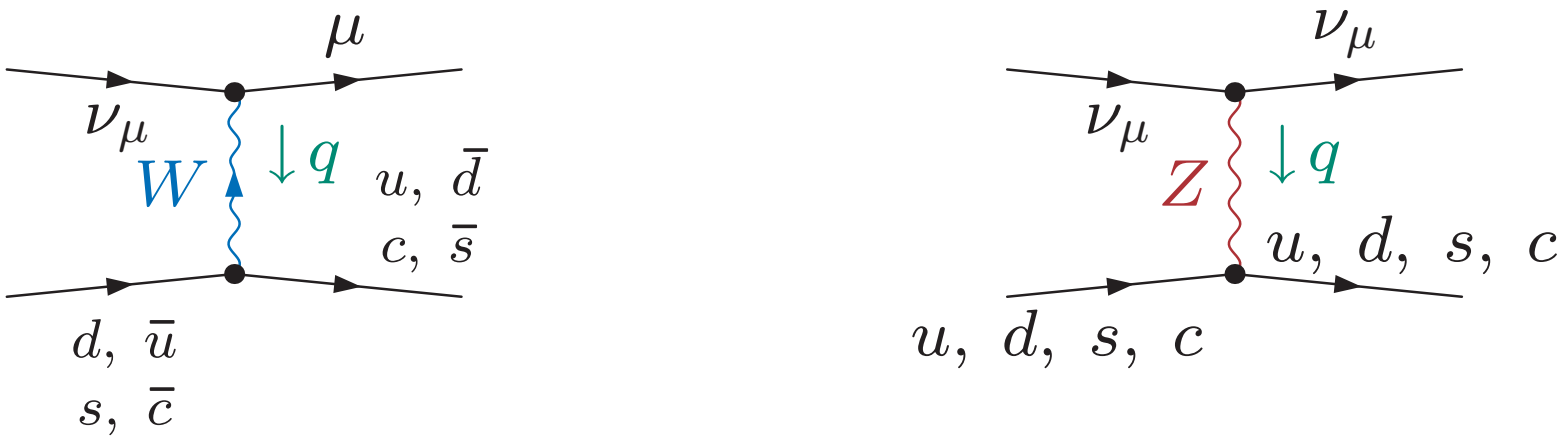
usefull combination : mass mixing term in stop-sector:

$$X_t := A_t - \mu/\tan\beta$$

• Deep inelastic νN scattering at NuTeV

– The NuTeV result and possible explanations

In the SM neutral (NC) and charged current (CC) neutrino nucleon scattering are described in LO by t-channel W and Z exchange.



At NuTeV ν_μ and $\bar{\nu}_\mu$ beams of a mean energy of 125 GeV were scattered off a target detector and the ratios

$$R^\nu = \frac{\sigma^\nu_{\mathrm{NC}}}{\sigma^\nu_{\mathrm{CC}}}\,, \qquad R^{\bar{\nu}} = \frac{\sigma^{\bar{\nu}}_{\mathrm{NC}}}{\sigma^{\bar{\nu}}_{\mathrm{CC}}}$$

were measured.

NuTeV measured also the weak mixing angle [NuTeV '02].

$$\sin^2\theta_w^{\text{on-shell}} = 0.2277 \pm 0.0013 \pm 0.0009$$

$\rightarrow$ This is about 3σ below the SM prediction !

But the measurement is indirect, using the measurements of $R^\nu, R^{\bar\nu}$ and making use of the Paschos-Wolfenstein relation

$$R^- = \frac{R^\nu - r R^{\bar\nu}}{1-r} = \frac{1}{2} - \sin^2\theta_w + \cdots , \qquad r = \frac{\sigma^{\bar\nu}_{\text{CC}}}{\sigma^{\nu}_{\text{CC}}} \approx \frac{1}{2} .$$

More precisely, ratios of counting rates

$$R^{\nu}_{\rm exp} = \frac{\#\text{ of NC-like } \nu \text{ events}}{\#\text{ of CC-like } \nu \text{ events}} \approx R^{\nu}, \quad R^{\bar{\nu}}_{\rm exp} = \frac{\#\text{ of NC-like } \bar{\nu} \text{ events}}{\#\text{ of CC-like } \bar{\nu} \text{ events}} \approx R^{\bar{\nu}}$$

are measured.

$R^{\nu}_{\rm exp}, R^{\bar{\nu}}_{\rm exp}$ can be related to $R^{\nu}, R^{\bar{\nu}}$ by a detailed MC physics simulation.

The deviation from the SM in terms of $R^{\nu}_{\rm exp}, R^{\bar{\nu}}_{\rm exp}$ are [NuTeV '02]:

$$\Delta R^{\nu} = R^{\nu}_{\rm exp} - R^{\nu}_{\rm exp}(SM) = -0.0032 \pm 0.0013\ ,$$
$$\Delta R^{\bar{\nu}} = R^{\bar{\nu}}_{\rm exp} - R^{\bar{\nu}}_{\rm exp}(SM) = -0.0016 \pm 0.0028\ .$$

$\rightarrow \Delta R^{\nu,\bar{\nu}}$: simple starting point for studying MSSM radiative corrections

Possible explanations :

- statistical fluctuation, errors underestimated ?
  - $\longrightarrow$ re-analyses of EW rad. corr.
    [Diener, Dittmaier, Hollik '03; Arbuzov, Bardin, Kalinovskaya '03]
- relevant SM effects neglected ?
  - $\longrightarrow$ asymmetry of strange sea-quarks in the nucleon ($s \neq \bar{s}$)
  - $\longrightarrow$ isospin violation ($u_p \neq d_n$)
  - $\longrightarrow$ nuclear effects
  - $\longrightarrow$ etc. ...
- new physics ?
  - $\longrightarrow$ modified gauge boson interactions (e.g. in extra dimensions)
  - $\longrightarrow$ non-renormalizable operators (suppressed by powers of $\Lambda^{-1}_{\text{new physics}}$)
  - $\longrightarrow$ leptoquarks (e.g. R parity violating SUSY)
  - $\longrightarrow$ SUSY loop effects (e.g. in MSSM)
  - $\longrightarrow$ etc. ...

[νN DIS at NuTeV, NuTeV result and explanations]

Although the NuTeV "anomaly" is far from being settled,
it is interesting, if the MSSM *could* account for such an effect.

Earlier Studies:

- Davidson et al. ['02] ; Kurylov, Ramsey-Musolf, Su ['04] :
  - momentum transfer $q = 0$ approximation
  - no detailed parameter dependence studied
  - no Parton Distribution Functions (PDFs) used

results so far: MSSM not responsible (size ok, but wrong sign)

- our calculation: try to include kinematic effects [OBr, Koch, Hollik '03]
  - full q^2-dependence
  - use PDFs
  - use NuTeV cuts on hadronic Energy in final state
  - use mean neutrino beam energy (125 GeV)

– MSSM radiative corrections to νN DIS

Definition of $\delta R^{\nu,\bar{\nu}} = R^{\nu,\bar{\nu}}_{\text{MSSM}} - R^{\nu,\bar{\nu}}_{\text{SM}}$

The difference between MSSM and SM prediction, $\delta R^n = R^n_{\text{MSSM}} - R^n_{\text{SM}}$ with $R^n = \sigma^n_{\text{NC}}/\sigma^n_{\text{CC}} (n = \nu, \bar{\nu})$, using

$$(\sigma^n_{\text{NC}})_{\text{NLO}} = (\sigma^n_{\text{NC}})_{\text{LO}} + \delta\sigma^n_{\text{NC}} \quad (n = \nu, \bar{\nu})$$
$$(\sigma^n_{\text{CC}})_{\text{NLO}} = (\sigma^n_{\text{CC}})_{\text{LO}} + \delta\sigma^n_{\text{CC}} \quad (n = \nu, \bar{\nu})$$

can be expanded in $\delta\sigma^n_{\text{NC}}$ and $\delta\sigma^n_{\text{CC}}$

$$\delta R^n = \left(\frac{\sigma^n_{\text{NC}}}{\sigma^n_{\text{CC}}}\right)_{\text{LO}} \left(\frac{(\delta\sigma^n_{\text{NC}})_{\text{MSSM}} - (\delta\sigma^n_{\text{NC}})_{\text{SM}}}{(\sigma^n_{\text{NC}})_{\text{LO}}} - \frac{(\delta\sigma^n_{\text{CC}})_{\text{MSSM}} - (\delta\sigma^n_{\text{CC}})_{\text{SM}}}{(\sigma^n_{\text{CC}})_{\text{LO}}} \right).$$

$\rightarrow$ Only differences between MSSM and SM rad. corr. and LO cross section expressions appear.

Because of R parity conservation in the MSSM:

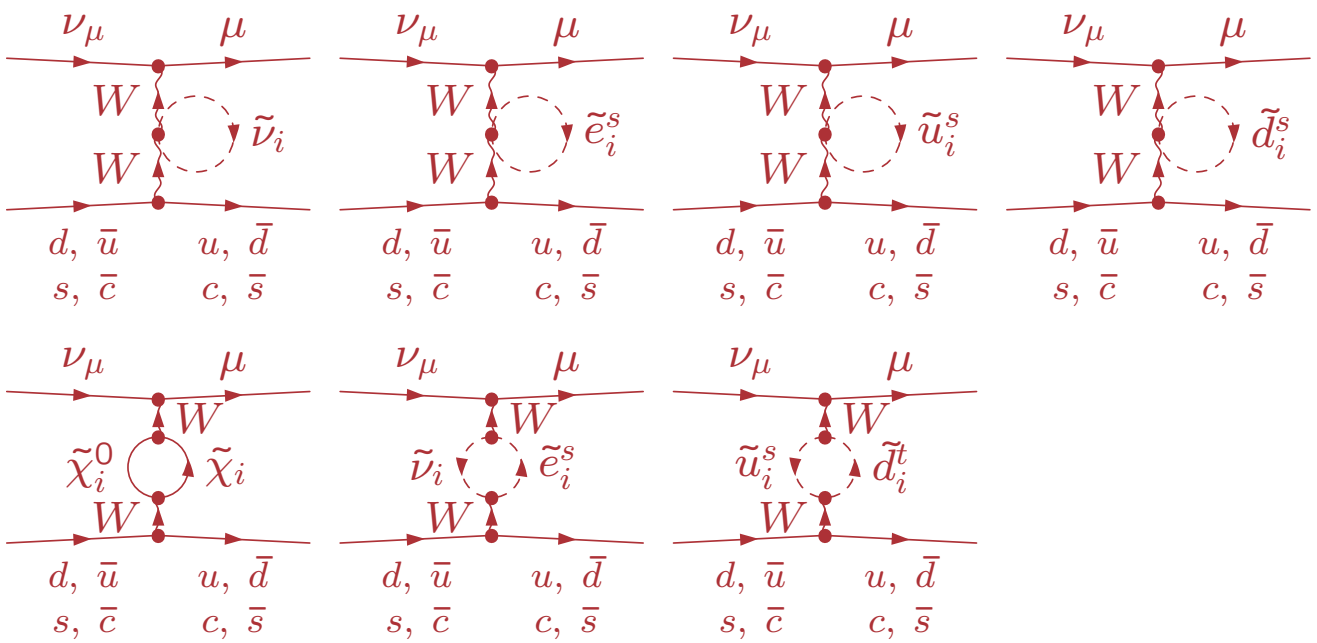
- Born cross section : SM = MSSM (very good approx.)
- real photon emission corrections : SM = MSSM (very good approx.)
- SM = MSSM for SM-like 1-loop graphs without virtual Higgs

Thus:

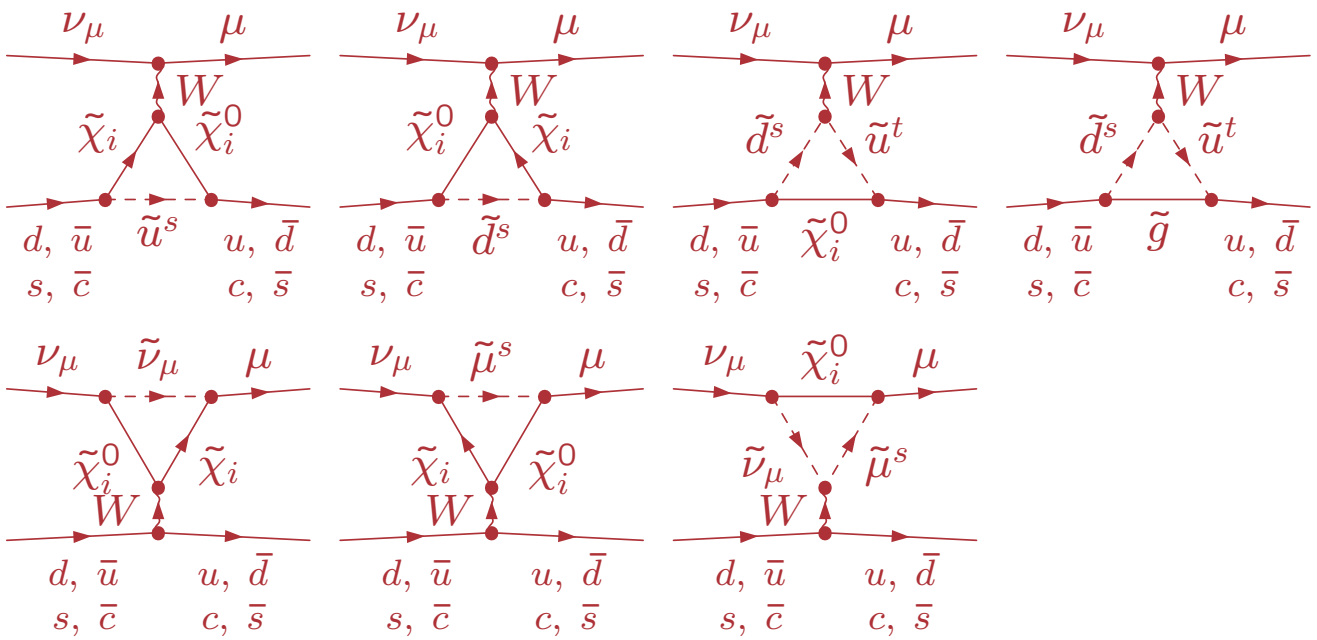
$$\delta R^n = \text{const.} \times \Big([\text{superpartner loops}] + [\text{Higgs graphs MSSM} - \text{Higgs graphs SM}] \Big) .$$

superpartner loop corrections :

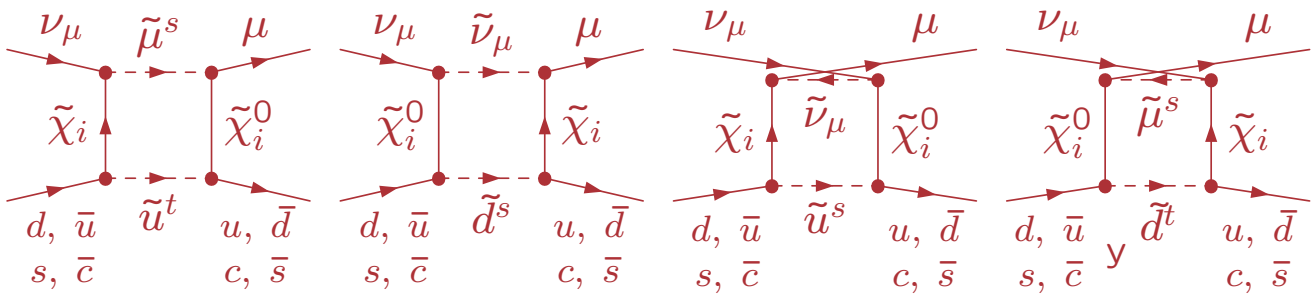
CC self energy insertions



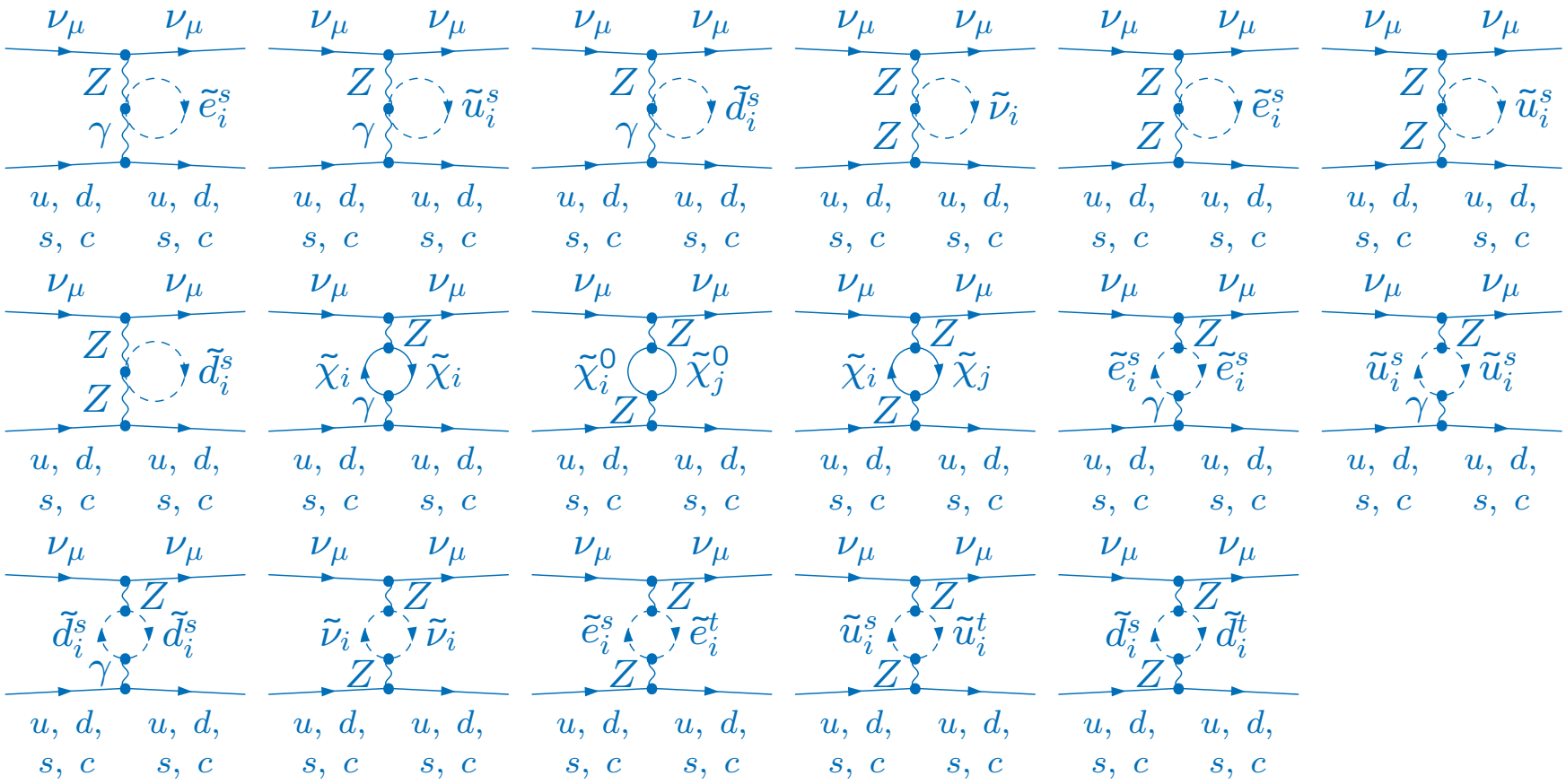
CC vertex corrections



CC box corrections

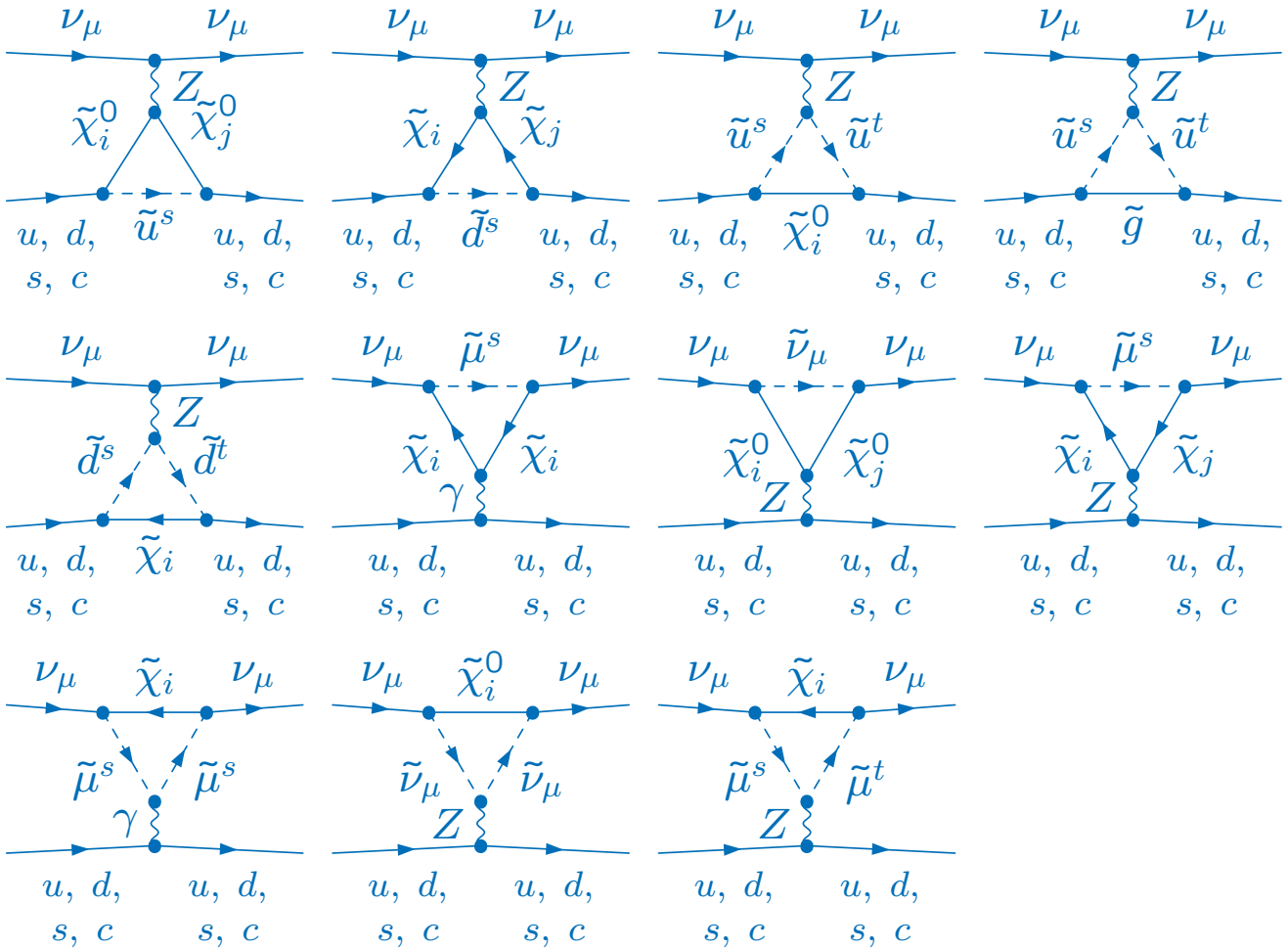


NC self energy insertions

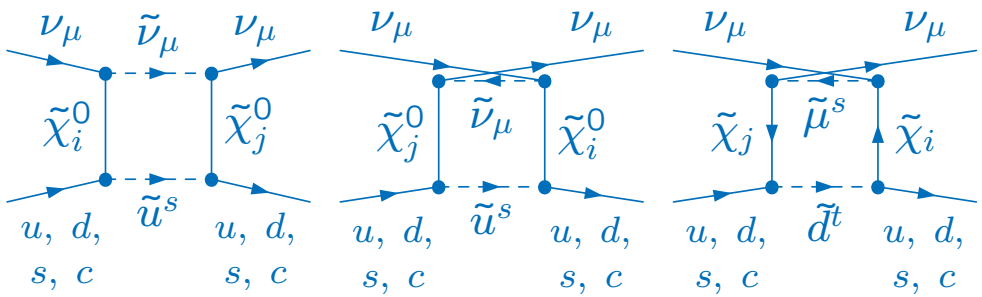


[νN DIS at NuTeV, MSSM radiative corrections]

NC vertex corrections



NC box corrections



The partonic processes were calculated using FeynArts/FormCalc.

[Küblbeck, Böhm, Denner'90],
[Eck '95], [Hahn, Perez-Victoria '99], [Hahn '01],
[Hahn, Schappacher '02]

see : www.feynarts.de

MSSM parameter scan

choice: $m_A = 500\,\text{GeV}$

$\longrightarrow$ SM-like Higgs sector

$\longrightarrow$ superpartner loops determine δR^n

restrictions taken into account:

- mass exclusion limits for Higgs bosons and superpartners
- $\Delta\rho$-constraint on sfermion mixing

quantities varied:

M_1, M_2	:	$50 \ldots 1000\,\text{GeV}$	μ	:	$-2000 \ldots 2000\,\text{GeV}$
M_{gluino}	:	$50 \ldots 1000\,\text{GeV}$	A_b, A_t	:	$-2000 \ldots 2000\,\text{GeV}$
$M_{\text{Sf.}}$	:	$50 \ldots 1000\,\text{GeV}$	$\tan\beta$	:	$1 \ldots 50$

MSSM parameter scan

goal : find regions of parameter space, where the MSSM might explain the NuTeV anomaly.
$\rightarrow$ difficult, large dimensionality of MSSM parameter space

scanning strategy : "adaptive scan" [OBr'04]:
exploit adaptive integration by importance sampling

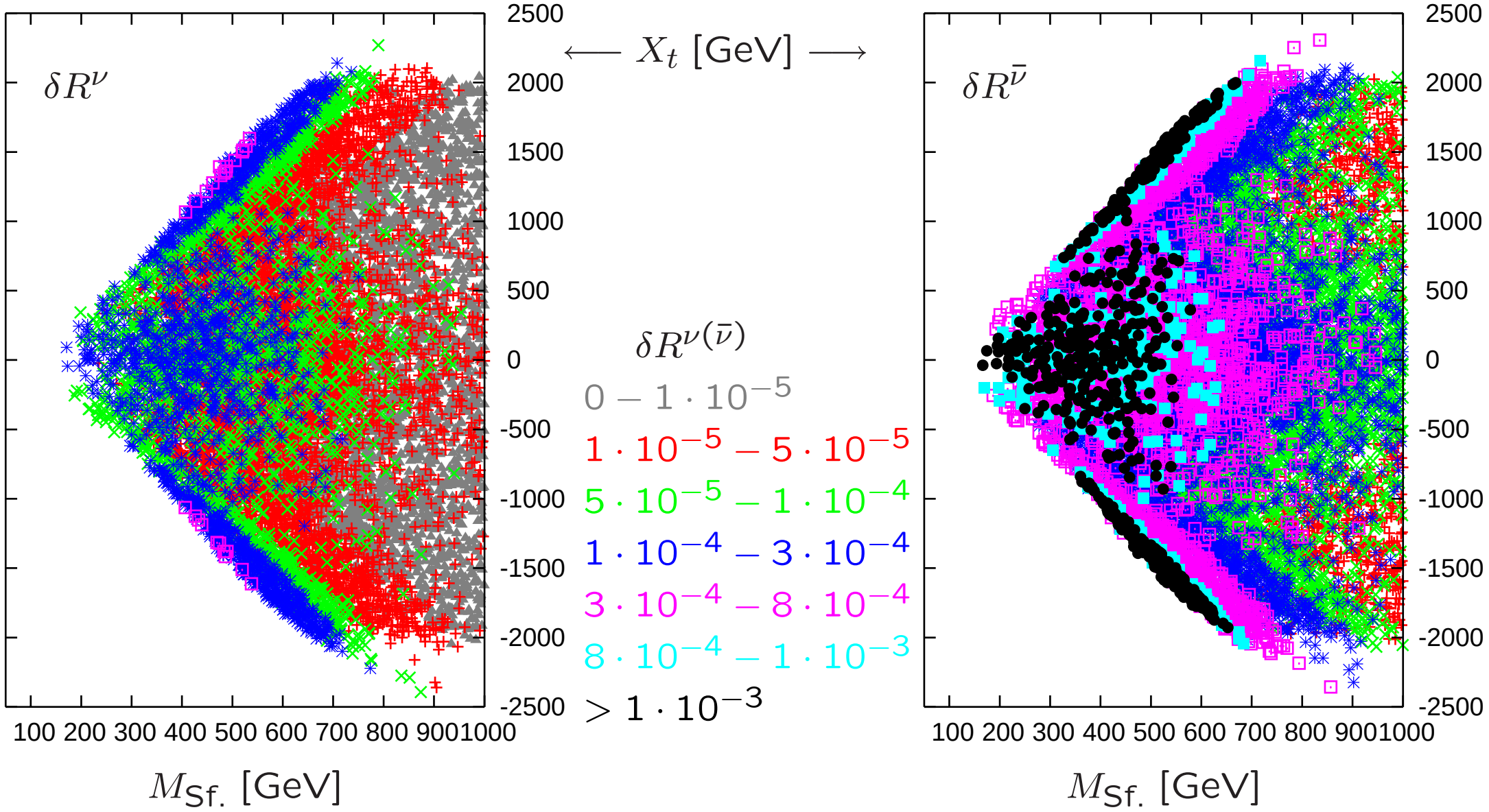
method: calculate an approximation to the integral

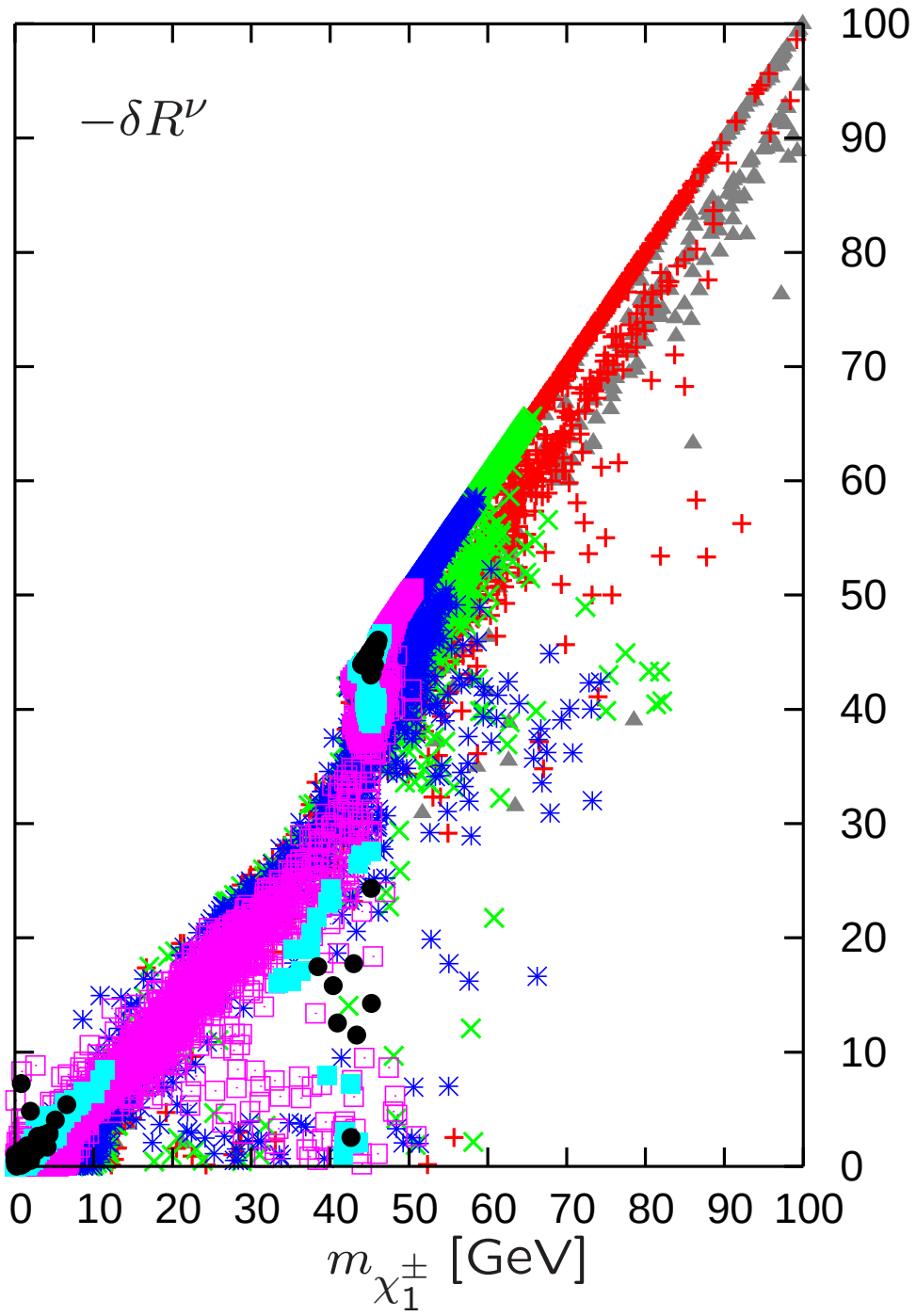
$$I = \int_{M_1^{\min}}^{M_1^{\max}} dM_1 \cdots \int_{d\tan\beta^{\min}}^{d\tan\beta^{\max}} d\tan\beta \; \delta R^{\nu(\bar{\nu})}(M_1, \ldots, \tan\beta)$$

with VEGAS and store the sampled parameter points.

$\rightarrow$ automatically, the sample points will be enriched in the regions of large $|\delta R^{\nu(\bar{\nu})}|$.

Scan for large values of $|\delta R^{\nu}|$ and $|\delta R^{\bar{\nu}}|$ with parameter restrictions





Scan for negative values of δR^ν without parameter restrictions

$-\delta R^\nu$

$0 - 1 \cdot 10^{-5}$

$1 \cdot 10^{-5} - 5 \cdot 10^{-5}$

$5 \cdot 10^{-5} - 1 \cdot 10^{-4}$

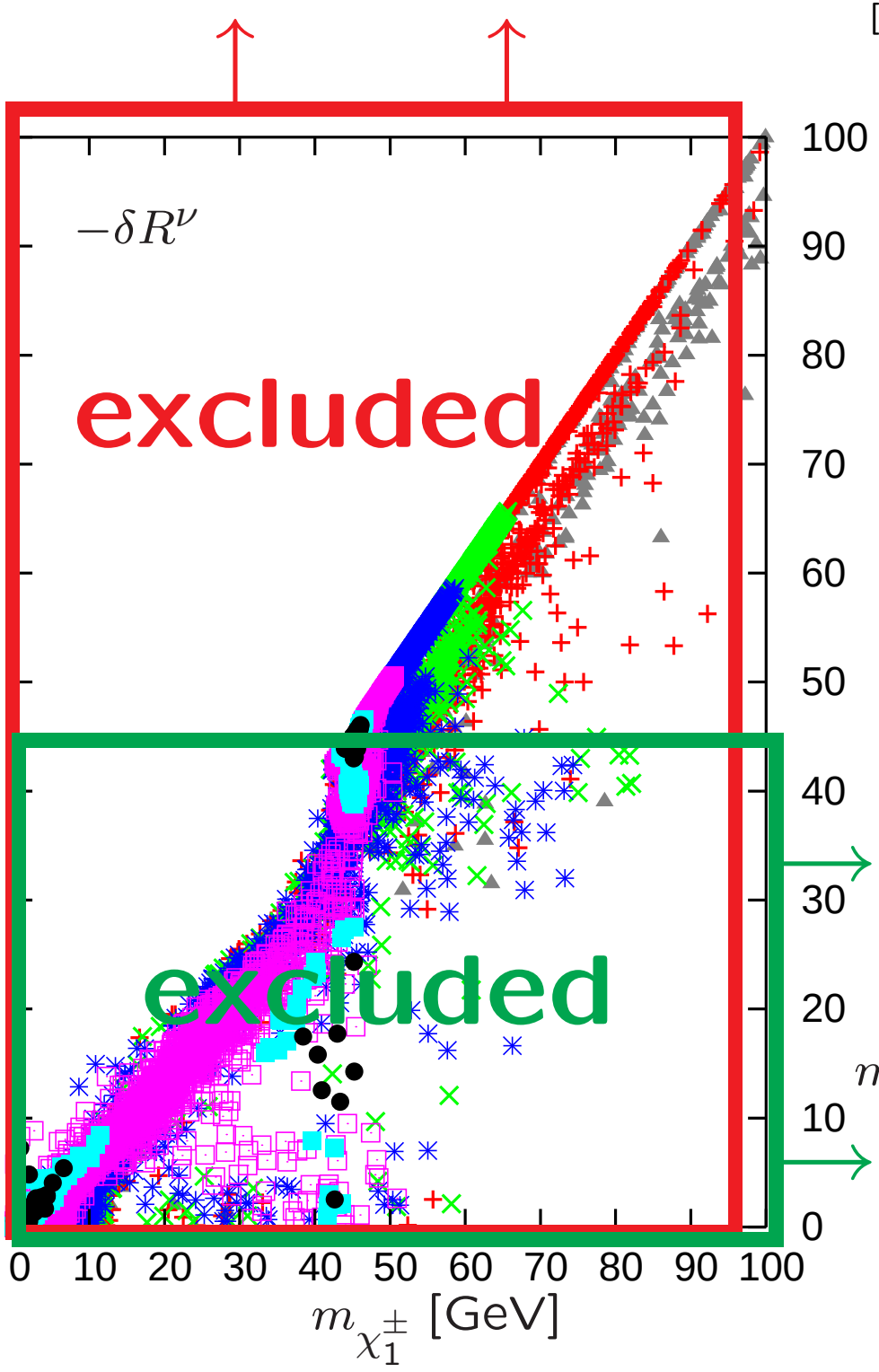
$1 \cdot 10^{-4} - 3 \cdot 10^{-4}$

$3 \cdot 10^{-4} - 8 \cdot 10^{-4}$

$8 \cdot 10^{-4} - 1 \cdot 10^{-3}$

$> 1 \cdot 10^{-3}$

[νN DIS at NuTeV, MSSM radiative corrections]



Scan for negative values of δR^ν without parameter restrictions

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$0 - 1 \cdot 10^{-5}$

$1 \cdot 10^{-5} - 5 \cdot 10^{-5}$

$5 \cdot 10^{-5} - 1 \cdot 10^{-4}$

$1 \cdot 10^{-4} - 3 \cdot 10^{-4}$

$3 \cdot 10^{-4} - 8 \cdot 10^{-4}$

$8 \cdot 10^{-4} - 1 \cdot 10^{-3}$

$> 1 \cdot 10^{-3}$

$m_{\chi_1^\pm} > 94\text{GeV}$

$m_{\chi_1^0} > 46\text{GeV}$

$\longrightarrow$ **all interesting regions excluded**

Summary

- Supersymmetry is *the* extension of Poincaré-symmetry which is consistent with relativistic quantum field theory

- The MSSM is the minimal phenomenological model to parametrise effects of supersymmetric field theory at the electroweak-scale

- The MSSM provides a rich set of new phenomena, but is in accord with present electroweak precision data

Summary [Deep inelastic νN scattering at NuTeV]

- The NuTeV measurement of $\sin^2\theta_w$ is intriguing but has to be further established (especially confirmation by other experiment(s) is desirable).

- Loop effects in the MSSM are most likely not responsible for the NuTeV "anomaly". (size can be right, but sign is wrong).

- To make sure, a full analysis, including the MSSM-SM Higgs sector differences, is needed (and planned).

- If the "anomaly" is established, interesting restrictions on the MSSM parameters arise.

Higgs Part

- Higgs bosons, SUSY and extended Models
  - Spontaneous symmetry breakdown, Higgs mechanism
  - Standard Model and extensions
- Higgs production at future hadron colliders
  - How to produce a Higgs boson ?
  - Neutral Higgs production overview
- $H^{\pm}W^{\mp}$ production @ LHC: MSSM vs. THDM
  - Charged Higgs search at LHC/Tevatron
  - MSSM/THDM $H^{\pm}W^{\mp}$ production

• 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,
which breaks gauge symmetry in ground state.

Thus, one major task in particle physics is:

to unravel the nature of
electroweak symmetry breaking.

different models realizing SSB

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

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

consequences:

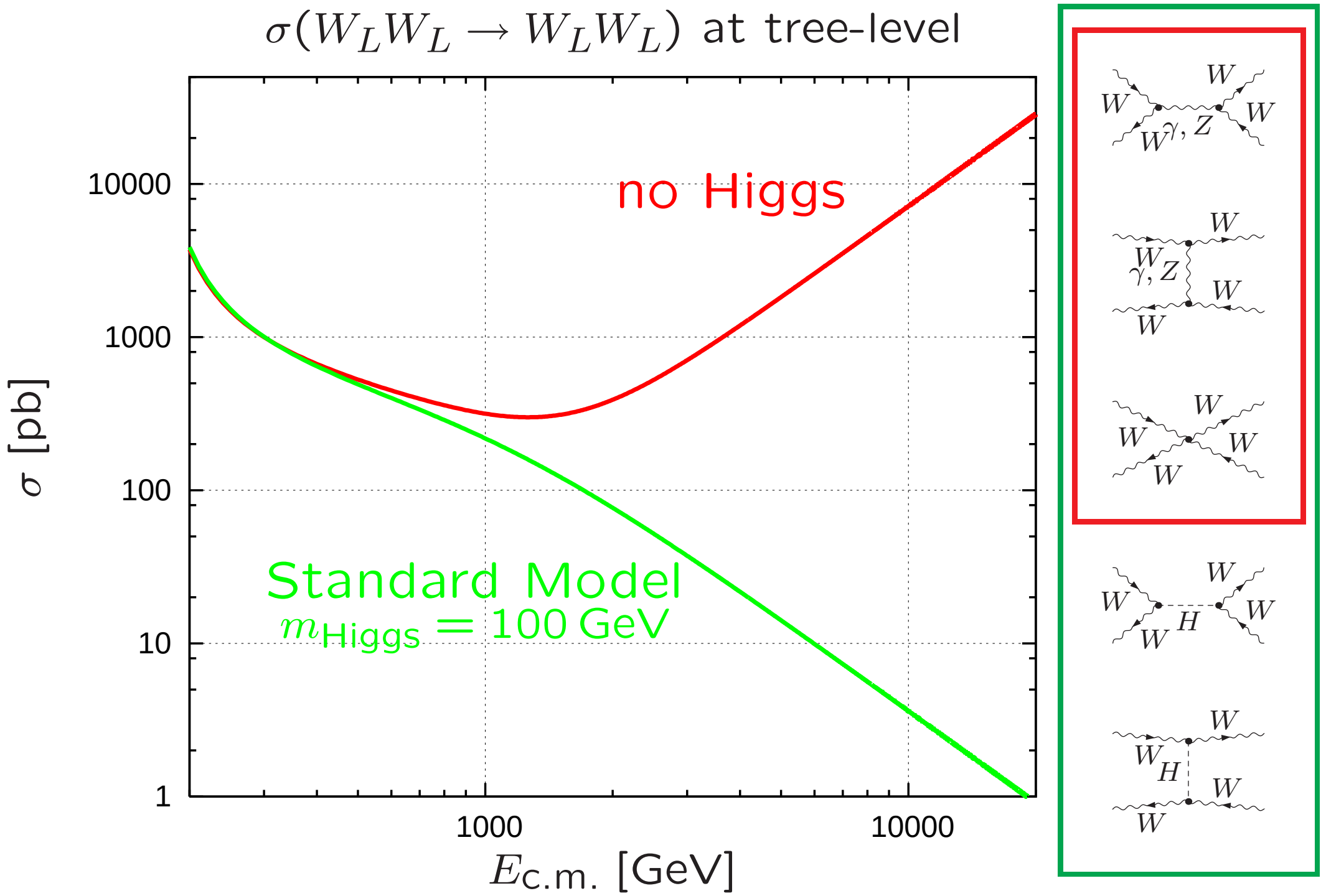
→ existence of Higgs particle(s)

→ theory may be applicable up to very high energy ($\sim M_{\text{GUT}}$ or M_{Planck}).

If so, then: Higgs is light, mass $m_H \lesssim 1\,\text{TeV}$

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

the Higgs mechanism


$\sigma(W_L W_L \to W_L W_L)$ at tree-level
no Higgs
Standard Model
$m_{\text{Higgs}} = 100\,\text{GeV}$
σ [pb]
10000
1000
100
10
1
1000
10000
$E_{\text{c.m.}}$ [GeV]
W
W
W
γ, Z
W
W
W
γ, Z
W
W
W
W
W
W
W
H
W
W
W
H
W
W

– Standard Model and extensions

Experimental situation so far:

- No Higgs signal.
- No significant deviation from SM.

Theory:

- Many distinct possibilities to realize the Higgs mechanism.

$\longrightarrow$ take extensions of the SM (Higgs sector) seriously

$\longrightarrow$ models have to meet constraints, like

- 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).

SM:

matter, gauge bosons + 1 Higgs doublet Φ

$\rightarrow$ 1 physical Higgs boson

THDM:

(two Higgs doublet model)

SM matter, SM gauge bosons

+ 2 Higgs doublets Φ_1, Φ_2

MSSM:

(minimal supersym. standard model)

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^-

note! : Charged Higgs bosons cannot appear with *one* Higgs doublet

$\rightarrow$ discovery of $H^\pm$: unambiguous sign of an extended Higgs sector

Consequences of SUSY for the MSSM Higgs sector

- The MSSM is *only* consistent with two Higgs doublets
- all Φ^4-interactions are determined by gauge couplings

  $\longrightarrow$ mass spectrum and interactions determined (at tree-level) by two input parameters $(m_{A^0}, \tan\beta = v_2/v_1)$ [instead of seven $(m_{h^0}, m_{H^0}, m_{A^0}, m_{H^\pm}, \lambda_5, \alpha, \tan\beta)$ in the THDM]

  $\longrightarrow$ there is an upper bound on the lightest neutral Higgs mass $(m_{h^0} \lesssim 135\,\text{GeV})$
- There are large quantum corrections (esp. to m_{h^0})

  $\longrightarrow$ Higgs properties depend on superpartners at the quantum level

  $\longrightarrow$ even 3-loop corr. to m_{h^0} are significant for future comparison of LHC data with theory

  $\longrightarrow$ m_{h^0} is a precision "observable"

present status: see [Degrassi, Heinemeyer, Hollik, Slavich, Weiglein '02]

• Higgs production at future hadron colliders

– How to produce a Higgs boson ?

Higgs mechanism $\longrightarrow$ Higgs couplings to all other particles $\propto$ mass

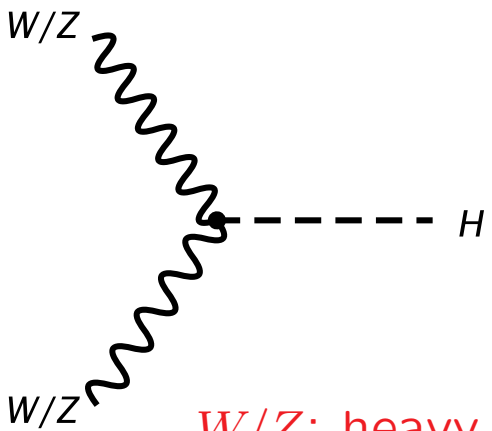
$\longrightarrow$ Problem: ordinary matter consists of

$\star$ e^-,u-, d-quarks : very light

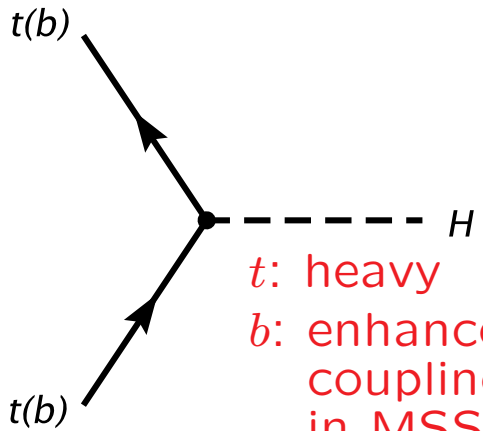
$\star$ with negligible couplings to the Higgs boson.

$\longrightarrow$ Thus: at colliders the Higgs couples to heavy intermediate particles with non-suppressed couplings to ordinary matter.

Therefore, most important couplings :

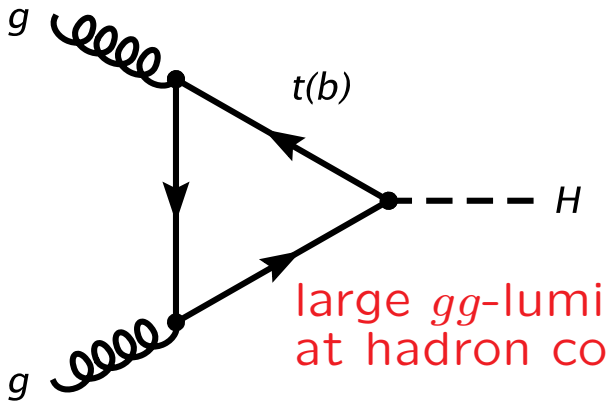


W/Z: heavy



t: heavy

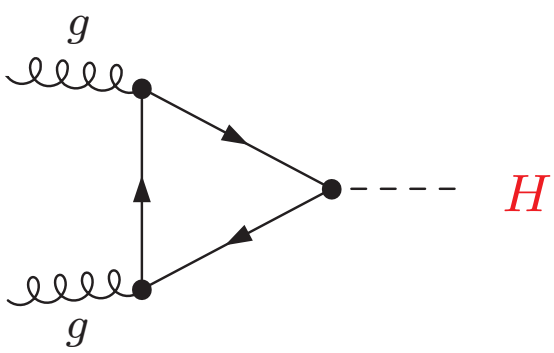
b: enhanced coupling in MSSM



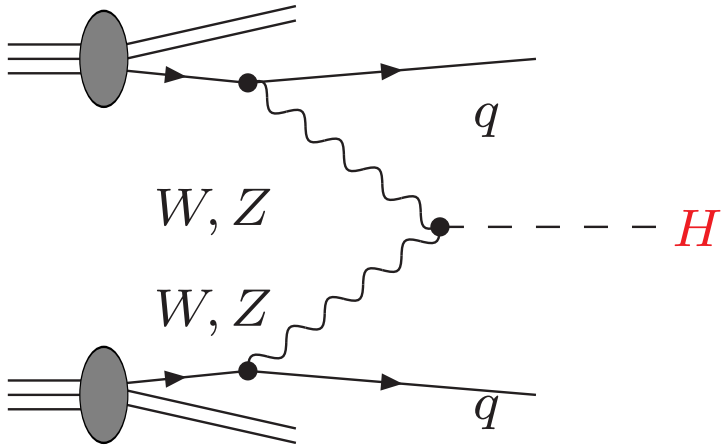
large gg-lumi at hadron colliders

– Neutral Higgs production overview

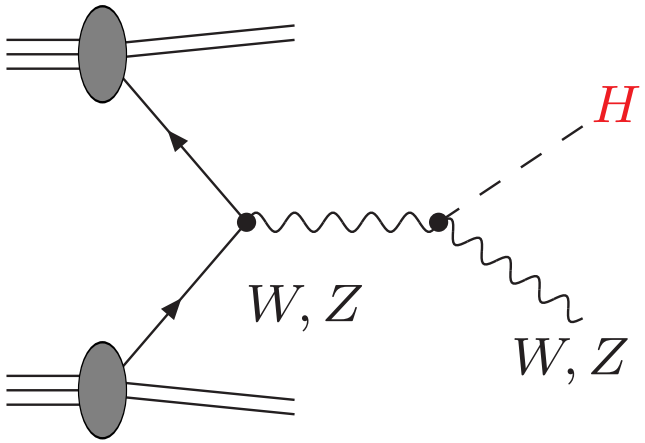
Important neutral Higgs Production Processes:



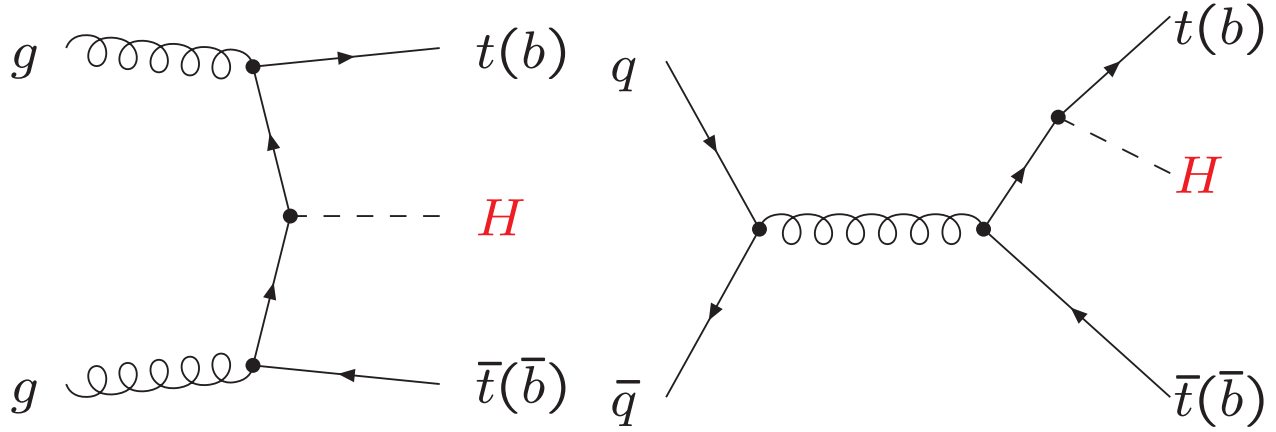
gluon fusion, $gg \to H$



vector boson fusion, $qq \to qqH$

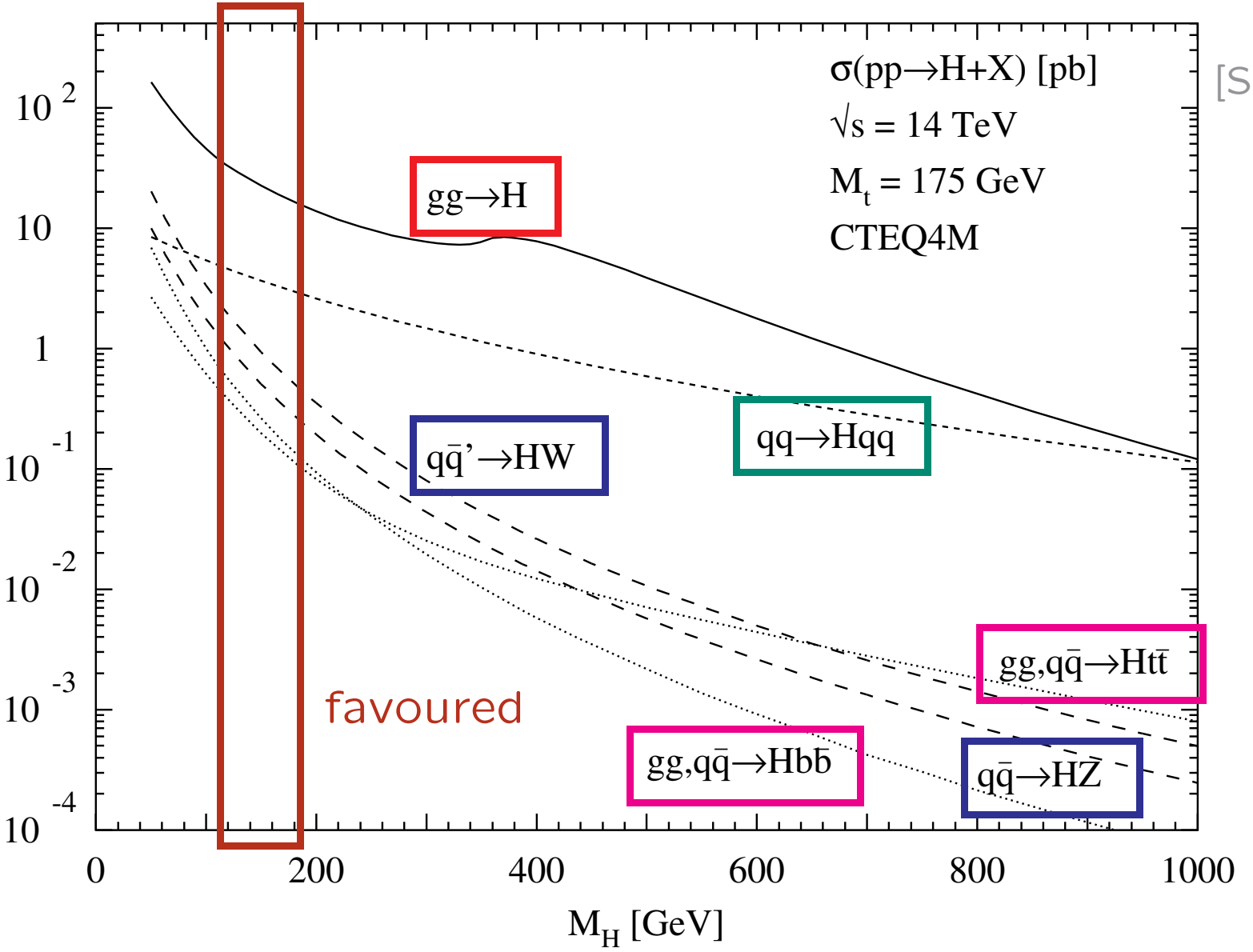


Higgs strahlung, $q\bar{q}' \to VH$



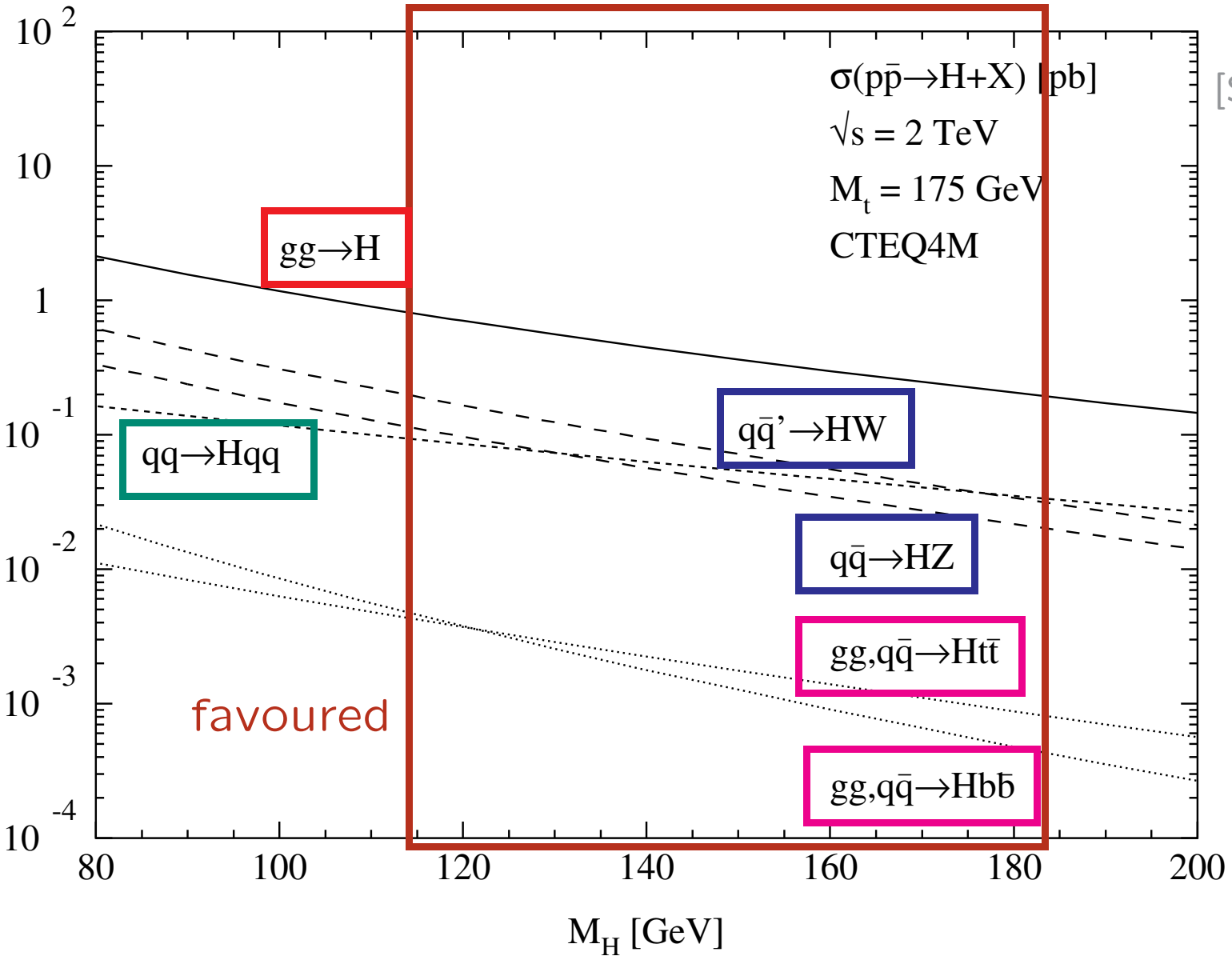
$t\bar{t}H$ $(b\bar{b}H)$ **production [&** $b\bar{b} \to H$ **if 5 flavors]**

Predictions for Standard Model Higgs production processes @ LHC :



[Spira '98]

Predictions for Standard Model Higgs production processes @ Tevatron :



[Spira '98]

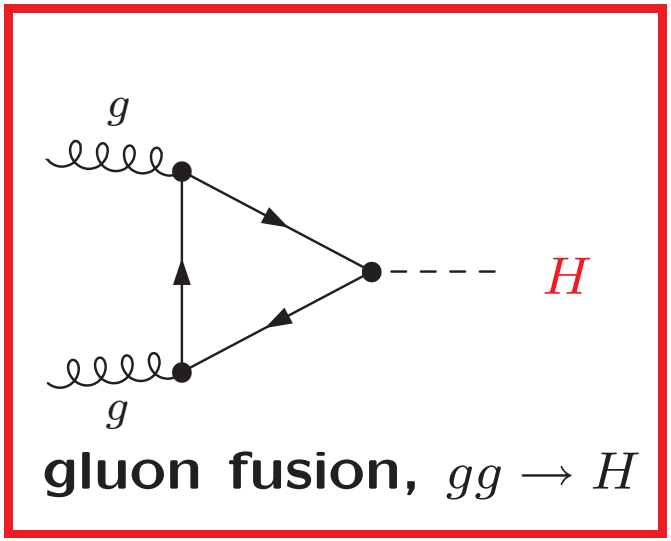
cross sections in the MSSM:

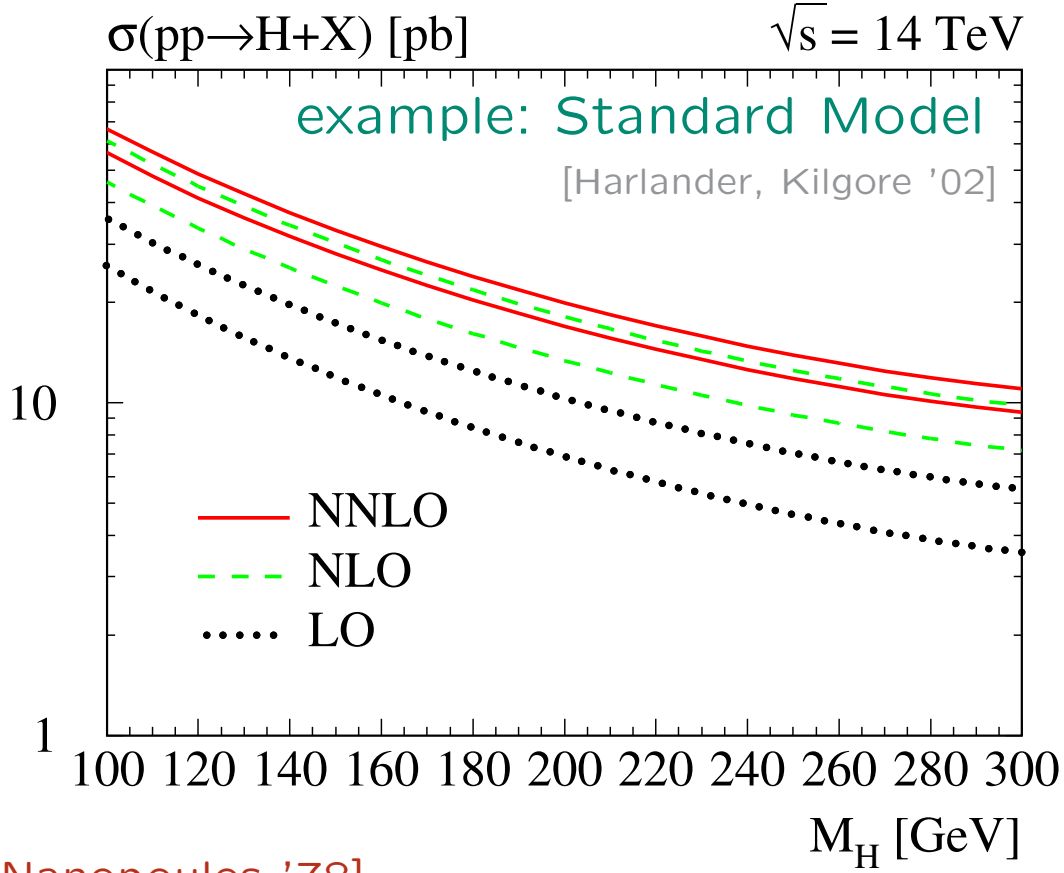
small $\tan\beta$ (say 3) :

- cross sections similar to SM
- gluon fusion, $\sigma(gg \longrightarrow h)$, dominant

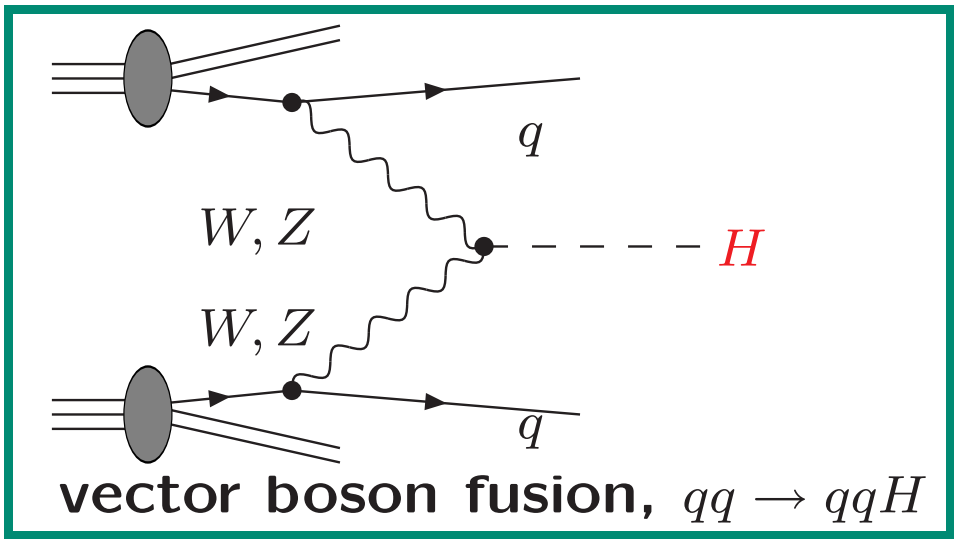
large $\tan\beta$ (say ≥ 30) :

- gluon fusion cross section larger than in SM
- b-quark processes gaining importance
- $\sigma(gg \longrightarrow h) \approx \sigma(gg, q\bar{q} \longrightarrow hb\bar{b})$
- Higgs strahlung unimportant





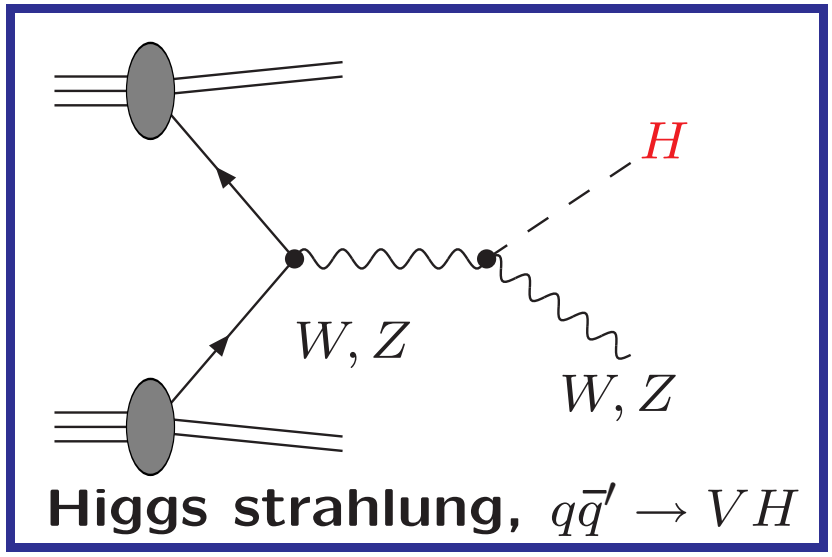
SM, LO [Georgi, Glashow, Machacek, Nanopoulos '78]
SM, NLO QCD [Dawson'91; Djouadi, Spira, Zerwas, Graudenz '91/'93]
SM, NNLO QCD [Harlander '00; Catani, de Florian, Grazzini '01; Harlander, Kilgore '01 & '02; Anastasiou, Melnikov '02; Ravindran, Smith, van Neerven '03]
SM, NLO EW [Djouadi, Gambino '94; Djouadi, Gambino, Kniehl '98; Aglietti, Bonciani, Degrassi, Vicini '04; Degrassi, Maltoni '04]
MSSM, NLO QCD, no superpartners [Djouadi, Spira, Zerwas, Graudenz '91/'93]
MSSM, NLO SUSY-QCD [Harlander, Steinhauser '04]



SM, LO [Cahn, Dawson '84; Kane, Repko, Rolnick '84]

SM, NLO QCD [Han, Valencia, Willenbrock ' 92; Figy, Oleari, Zeppenfeld' 03; Berger, Campbell '04]

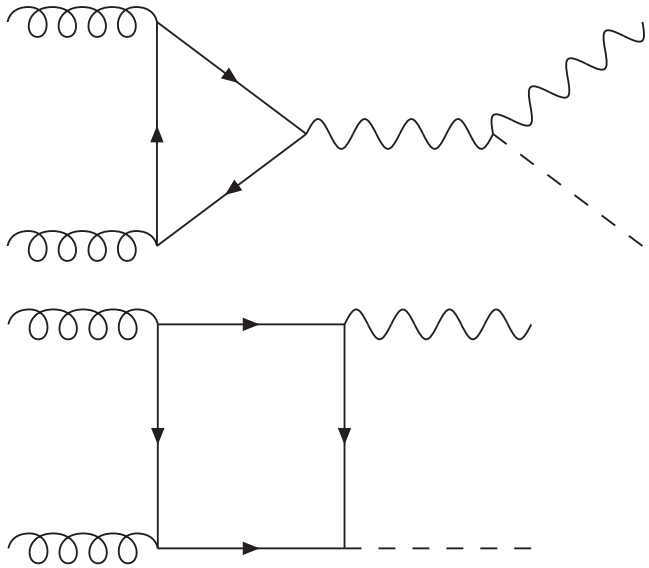
MSSM, NLO SUSY-QCD [Djouadi, Spira '00]



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

note! : additional parton process @ NNLO

[Dicus, Kao '88; Kniehl '90]



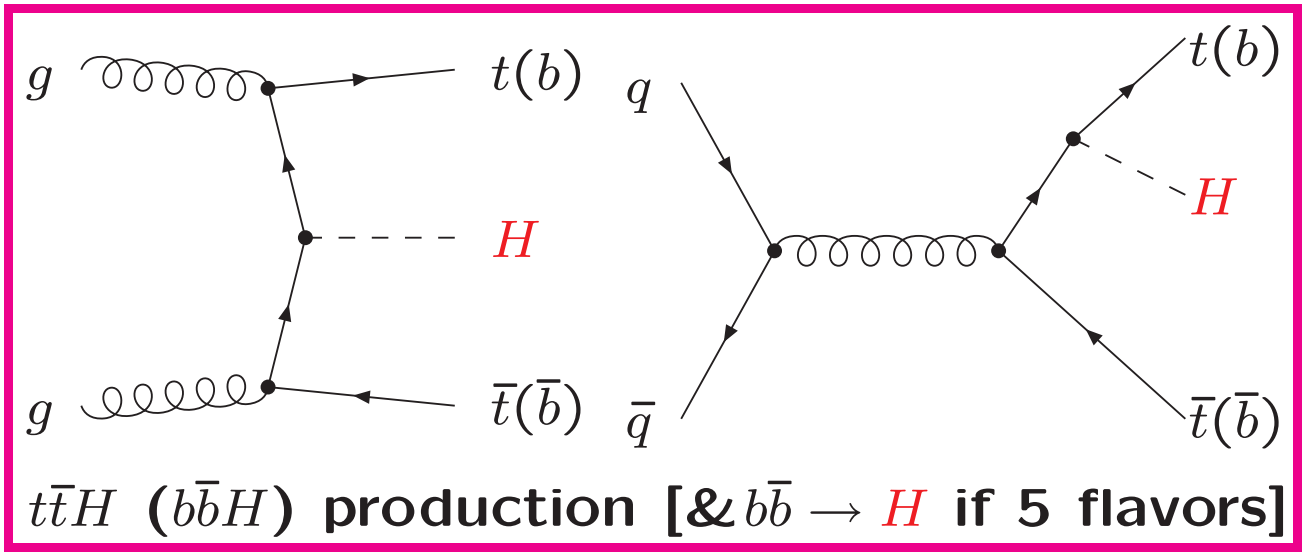
SM, LO [Glashow, Nanopoulos, Yildiz '78]

SM, NLO QCD [Han, Willenbrock ' 91]

SM, NNLO QCD [OBr, Djouadi, Harlander '03]

SM, NLO EW [Ciccolini, Dittmaier, Krämer '03]

MSSM, NLO SUSY-QCD [Djouadi, Spira '00]



$t\bar{t}H$ ($b\bar{b}H$) production [&$b\bar{b} \to H$ if 5 flavors]

SM, LO ($t\bar{t}H$) [Kunszt '84]

SM, NLO QCD ($t\bar{t}H$) [Beenakker, Dittmaier, Krämer, Plümper, Spira, Zerwas '01; Dawson, Jackson, Orr, Reina, Wackeroth '01-'03]

SM, NLO QCD ($b\bar{b}H$) [Dittmaier, Krämer, Spira '03; Dawson, Jackson, Reina, Wackeroth '03]

SM, NNLO QCD ($b\bar{b} \to H$) [Harlander, Kilgore '03]

MSSM, LO, $Q\bar{Q} \to H, gg \to Q\bar{Q}H$ ($Q = t, b$) [Dicus, Willenbrock '89]

MSSM, NLO QCD, no superpartners [Dawson, Jackson, Reina, Wackeroth '03]

• $H^{\pm}W^{\mp}$ production @ LHC: MSSM vs. THDM

discovery of $H^{\pm}$: unambiguous sign of an extended Higgs sector

– Charged Higgs search at LHC/Tevatron

- $m_{H^{\pm}} < m_t$:

  mainly via $t \to H^+ b$ and c.c. in $t\bar{t}$ events.

- $m_{H^{\pm}} > m_t$:

  mainly via $gb \to tH^+$, $gg \to tbH^+$

  [LO: Bawa, Kim, Martin '90; NLO QCD: Zhu '03; Plehn '03; Berger et al. '03]

  other processes with (much) smaller c.s. :
  $gg/b\bar{b} \to H^{\pm}W^{\mp}$ [...] and $gg/q\bar{q} \to H^+H^-$

  [Krause et al. '98; OBr, Hollik '99; Barrientos, Kniehl '99]

most viable Signal:

excess of tau events

from the decays $H^+ \to \tau^+\nu_\tau$ and c.c.

– MSSM/THDM $H^{\pm}W^{\mp}$ production

Why study $H^{\pm}W^{\mp}$ production?

$\longrightarrow$ processes (partly) loop-induced

$\longrightarrow$ loop-induced processes are strongly dependent
on virtual particles in the loop

$\longrightarrow$ the $W^{\pm}H^{\mp}$ production cross section is strongly model dependent

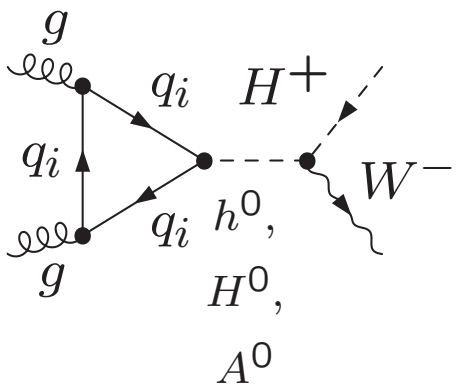
$\longrightarrow$ with a measurement of the cross section one would

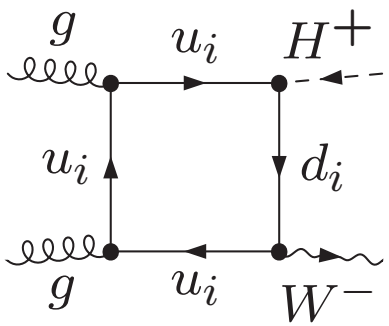
gain information on the underlying model

(e.g. MSSM, THDM).

gluon fusion

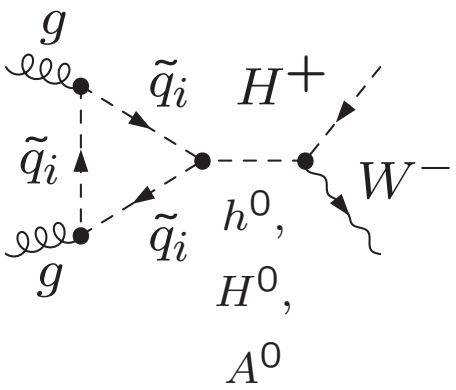
THDM amplitude

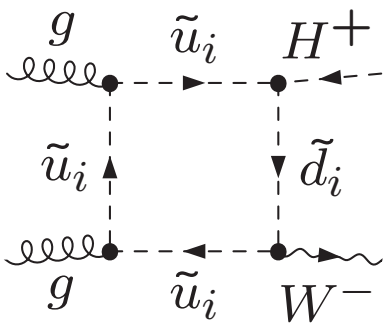




+ more

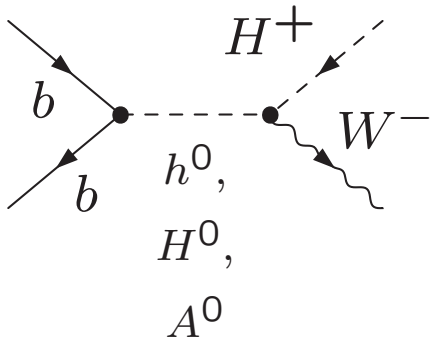
squark amplitude

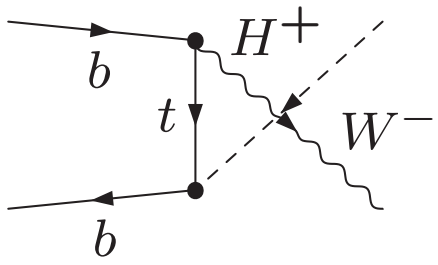




+ more

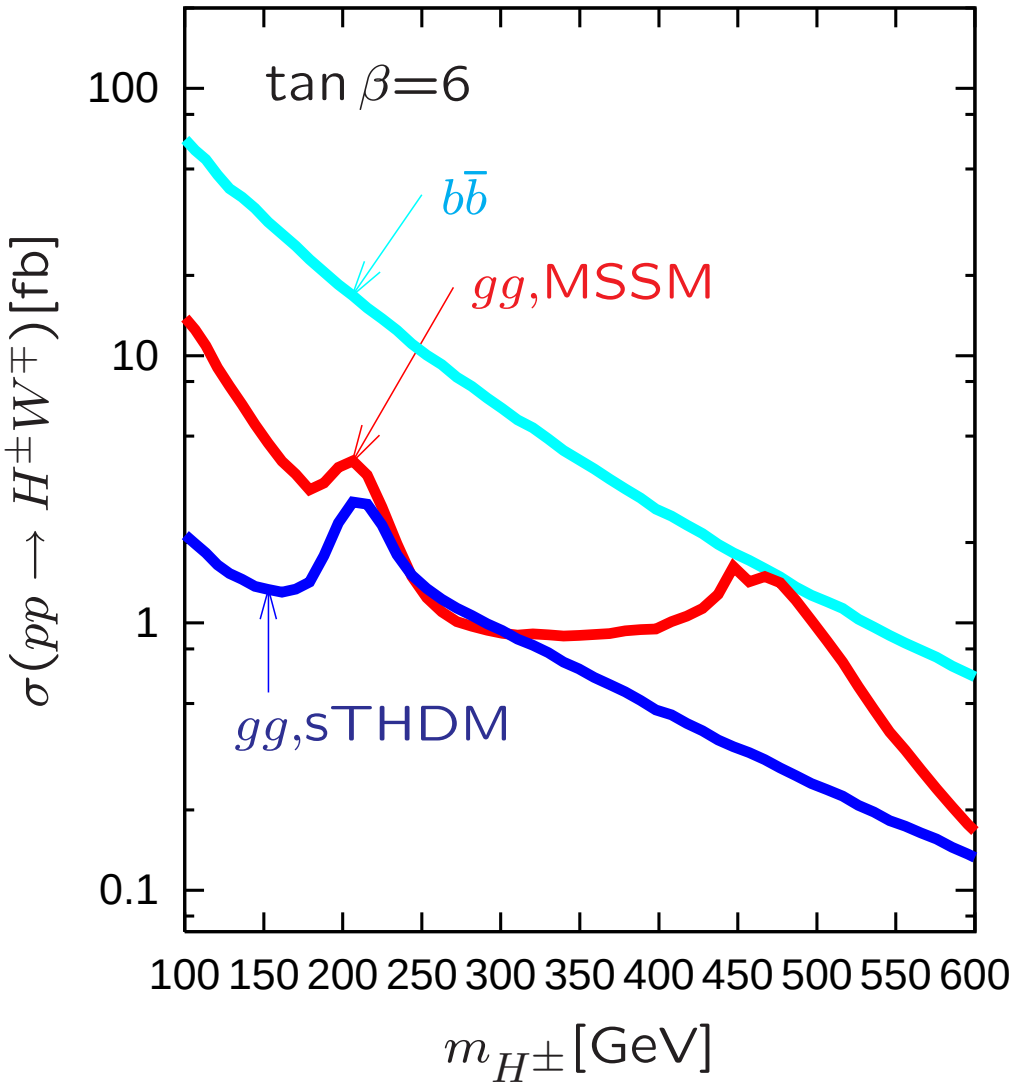
$b\bar{b}$ annihilation

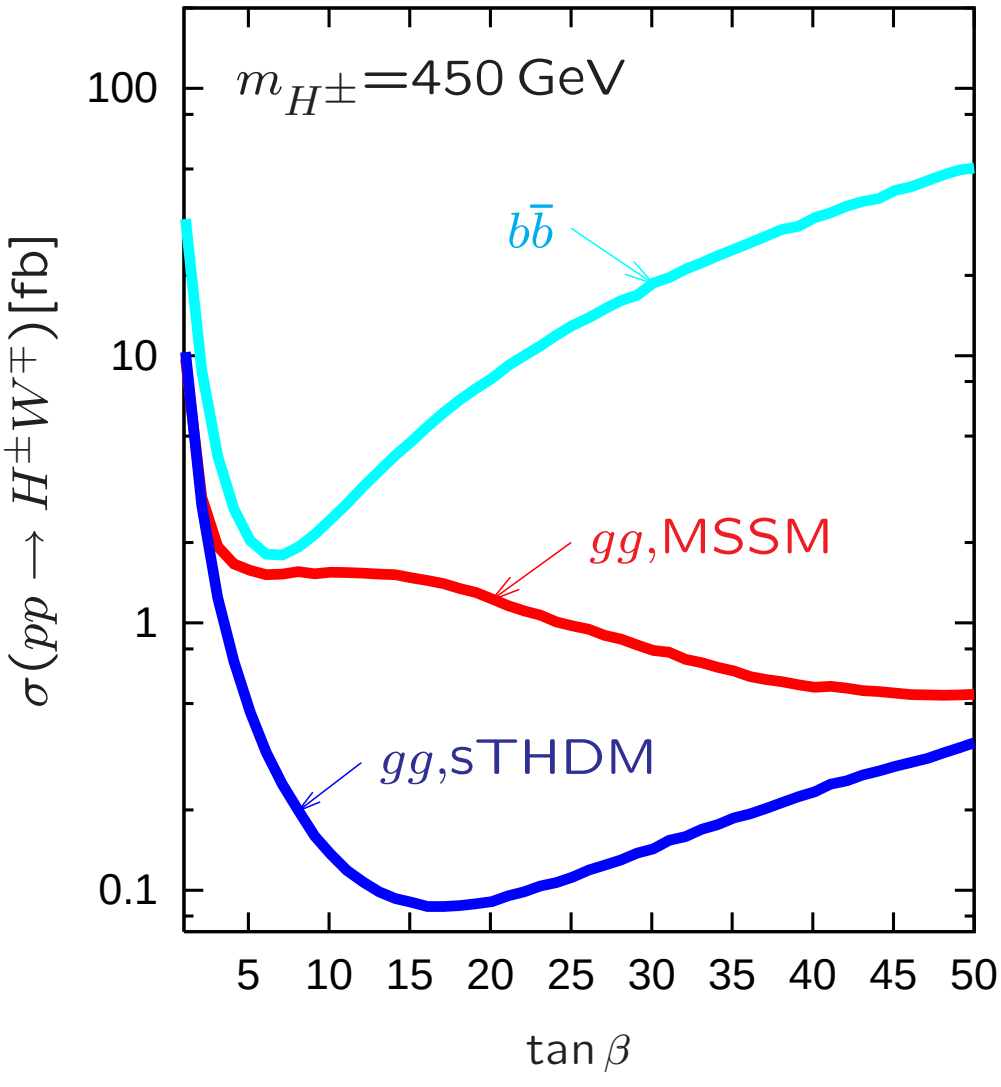




[gg: THDM: Dicus et al. '89; MSSM: Barrientos, Kniehl '99-'00;
OBr, Hollik, Kanemura '00; $b\bar{b}$: MSSM, NLO QCD: Hollik, Zhu '01]

inclusive $H^{\pm}W^{\mp}$ cross section at the LHC





MSSM versus THDM

MSSM:

interesting feature of $gg \to H^{\pm}W^{\mp}$:

strong negative interference between Δ– and $\Box$–amplitudes,

$$\text{i.e. } |\Delta|^2 \approx |\Box|^2 \approx (10 - 100) \cdot |\Delta + \Box|^2$$

reason: Higgs mass relations in the MSSM

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

$\to$ Δ–amplitudes cannot decouple from the process

$\to$ no resonant s-channel Higgs exchange possible

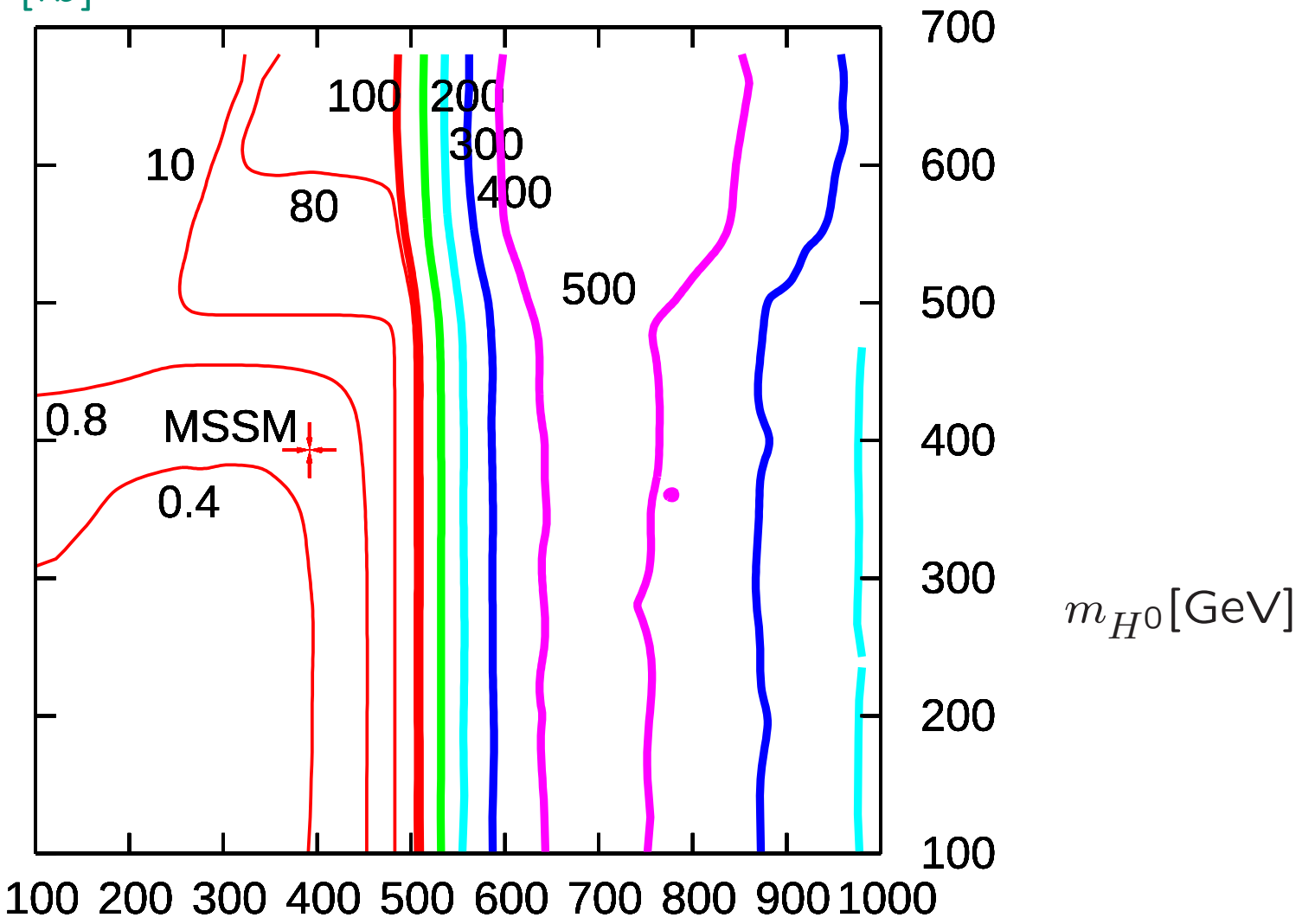
$\to$ negative interference unavoidable

THDM:

All this need not be true !

$\to$ cross section may be much larger than in the MSSM

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



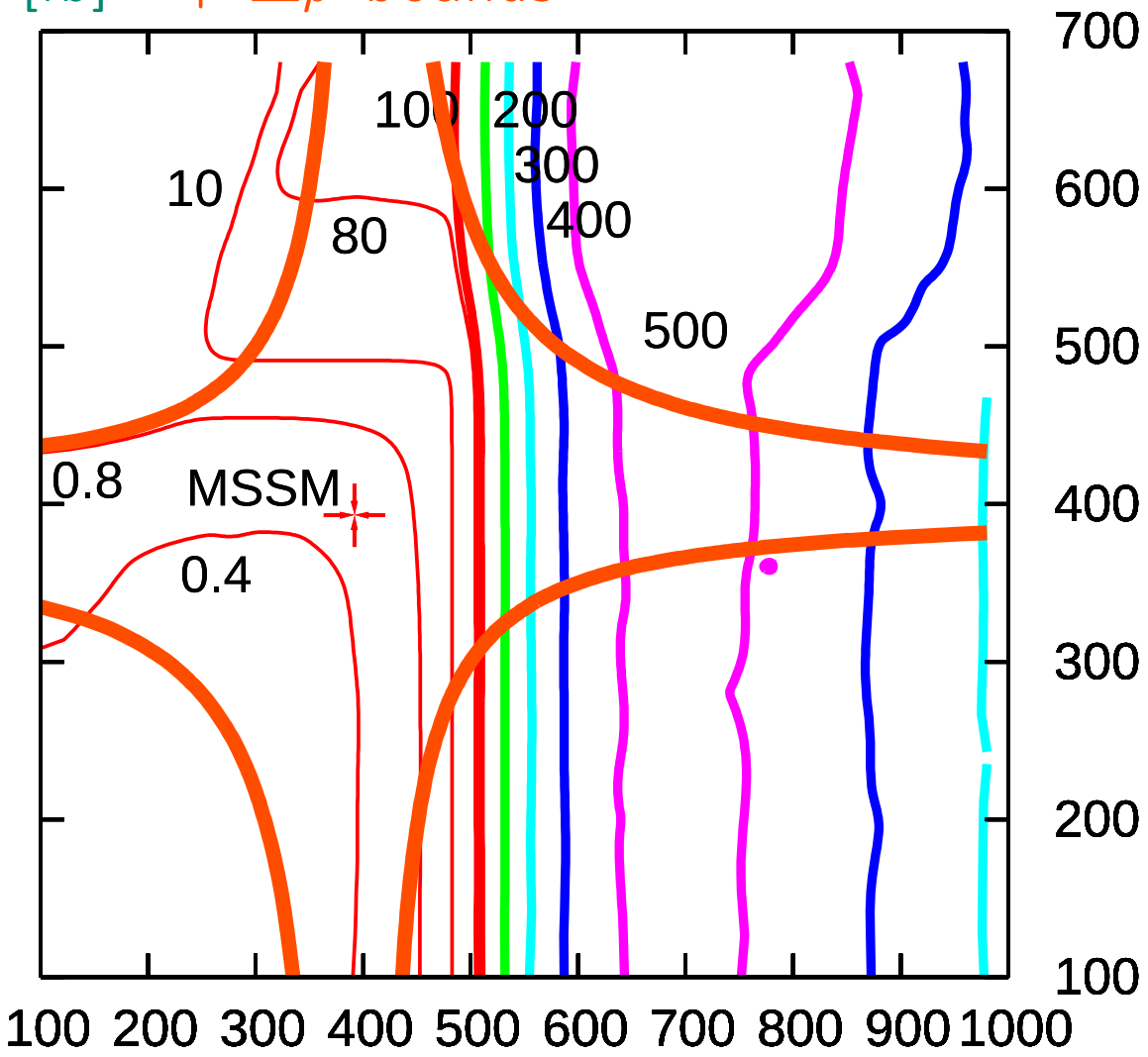
m_{H^0}[GeV]

m_{A^0}[GeV]

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

[Asakawa, OBr, Kanemura, work in progress]

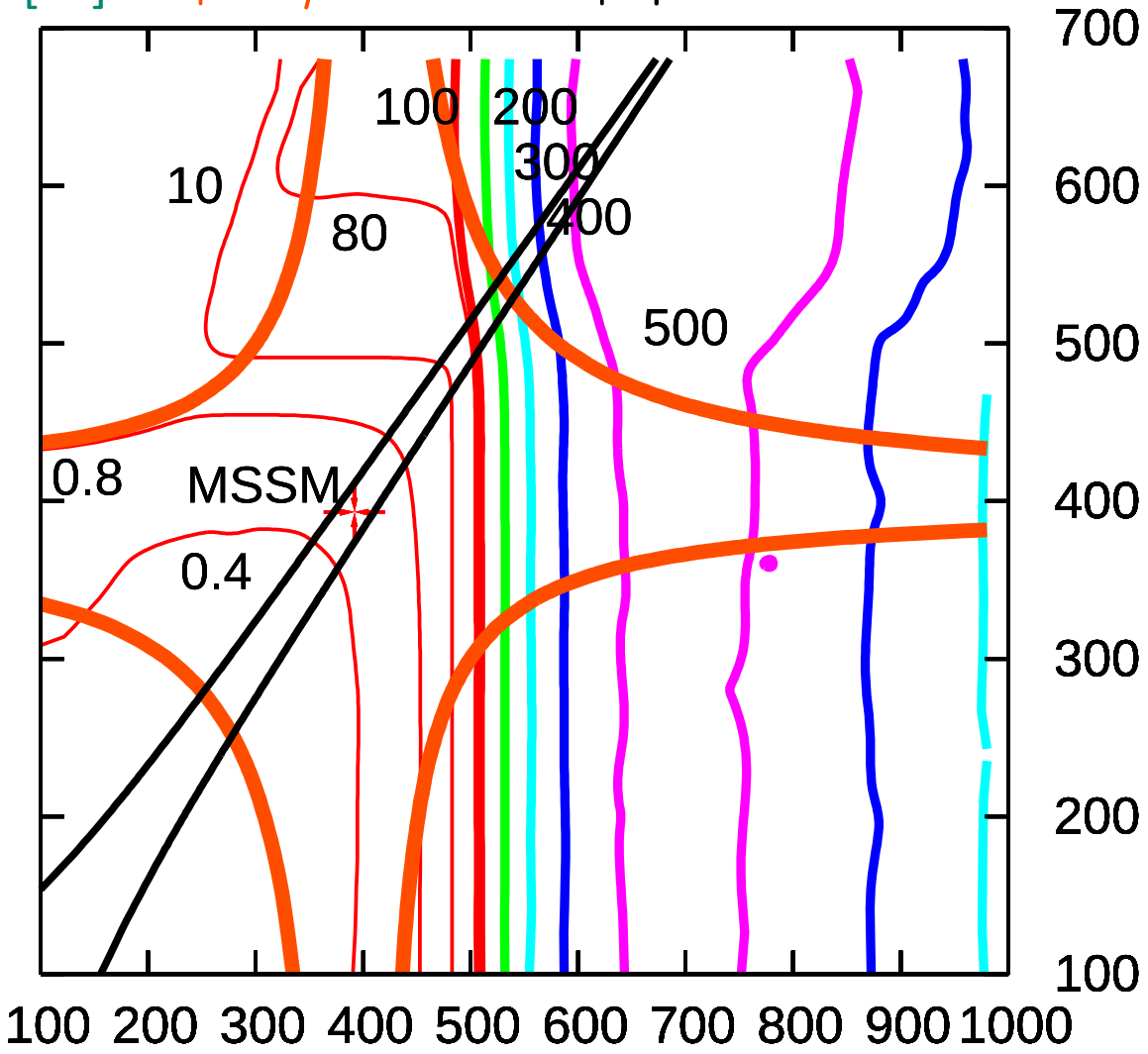
$\sigma(pp \to W^{\pm}H^{\mp})$ [fb] + $\Delta\rho$–bounds



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

[Asakawa, OBr, Kanemura, work in progress]

$\sigma(pp \to W^{\pm}H^{\mp})$ [fb] + $\Delta\rho$–bounds + perturbative unitarity bounds



m_{H^0}[GeV]

m_{A^0}[GeV]

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

[Asakawa, OBr, Kanemura, work in progress]

Summary

- The Higgs mechanism is an attractive theoretical description of massive vector bosons which is consistent up to very high energy

- The search for the Higgs boson(s) consists of
  * finding the Higgs
  * measuring Higgs properties (e.g. self-couplings)
  * determining the underlying model

Summary [$H^{\pm}W^{\mp}$ Production at the LHC: MSSM versus THDM]

- $H^{\pm}W^{\mp}$ production is no discovery process at the LHC
- studying $H^{\pm}W^{\mp}$ production at the LHC may help to gain information about the underlying model
- the $H^{\pm}W^{\mp}$ production cross section in the THDM can be much larger than in the MSSM