Probing triple Higgs couplings at colliders

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Outline

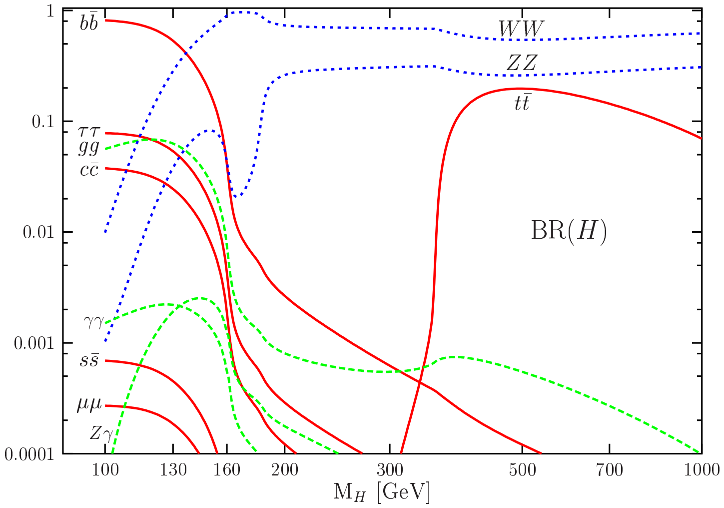
- Introduction: Higgs production and decays
- Two Higgs Doublets Models (2HDM) and its Decoupling regime
- Challenge of the decoupling limit
- Triple Higgs coupling from $h^0 \to \gamma\gamma$, $h^0 \to b\bar{b}$
- Triple Higgs couplings at LHC, ILC and $\gamma\gamma$
- Conclusions

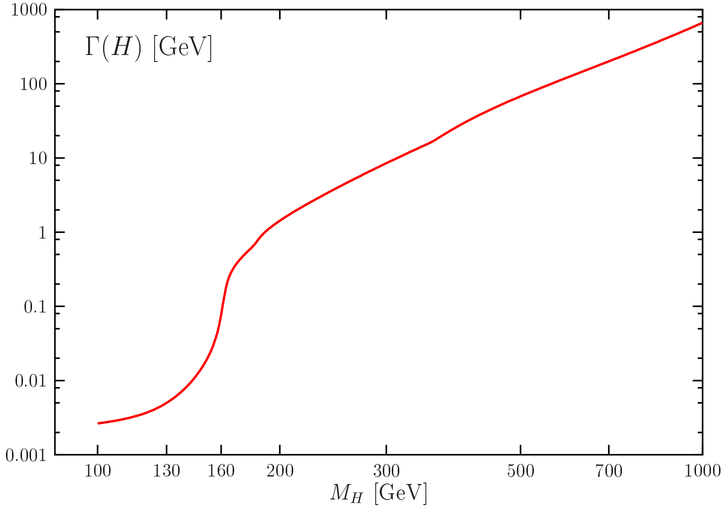
	Experiment	**SM**	Pull
A_{LR}	0.1513 (21)	0.1480	1.6
A^l_{FB}	0.01714 (95)	0.01642	0.8
$A_{e,\tau}$	0.1465 (32)	0.1480	-0.5
A^b_{FB}	0.0992 (16)	0.1037	-2.8
A^c_{FB}	0.0707 (35)	0.0741	-1.0
Q_{FB}	0.23240 (120)	0.23140	-0.8
m_W	80.398 (25)	80.374	0.9
Γ_Z	2495.2 (23)	2495.9	0.3
R_ℓ	20.767 (25)	20.744	0.9
σ_h	41.540 (37)	41.477	1.7
R_b	0.21629 (66)	0.21586	0.7
R_c	0.1721 (30)	0.1722	-0.04
A_b	0.923 (20)	0.935	-0.6
A_c	0.670 (27)	0.668	0.07
m_t	172.6 (1.4)	172.3	0.2
$\Delta\alpha_5(m_Z)$	0.02758 (35)	0.02768	-0.3
$\alpha_S(m_Z)$		0.1186	
m_H		85	
$m_H(95\%)$		148	
χ^2/dof		17.3/12	
CL(χ^2)		0.14	

M.Chanowitz 0904.3570

- Best fit analysis: $M_H = 84^{+34}_{-26}$ GeV which gives $M_H \lesssim 154$ GeV at 95% CL. (LEP Higgs Working Group).
- New analysis with new fitting program gives $M_H = 116.4^{+18.3}_{-1.3}$ GeV H.Flacher et al, arXiv:0811.0009 [hep-ph]
- LEPII Experiments: $M_H > 114.4$ GeV
- Unitarity constraint: $M_H \lesssim 700$ GeV
- Requiring the SM to be extended up to $\Lambda_{GUT} = 10^{16}$ GeV, one can get $130 \lesssim M_H \lesssim 180$ GeV.
- If the $M_H \gtrsim 200$ GeV, then there should be an additional new ingredient that is relevant at the EWSB scale.

Higgs decays





- At hadron colliders (LHC, Tevatron) the relevant processes are:

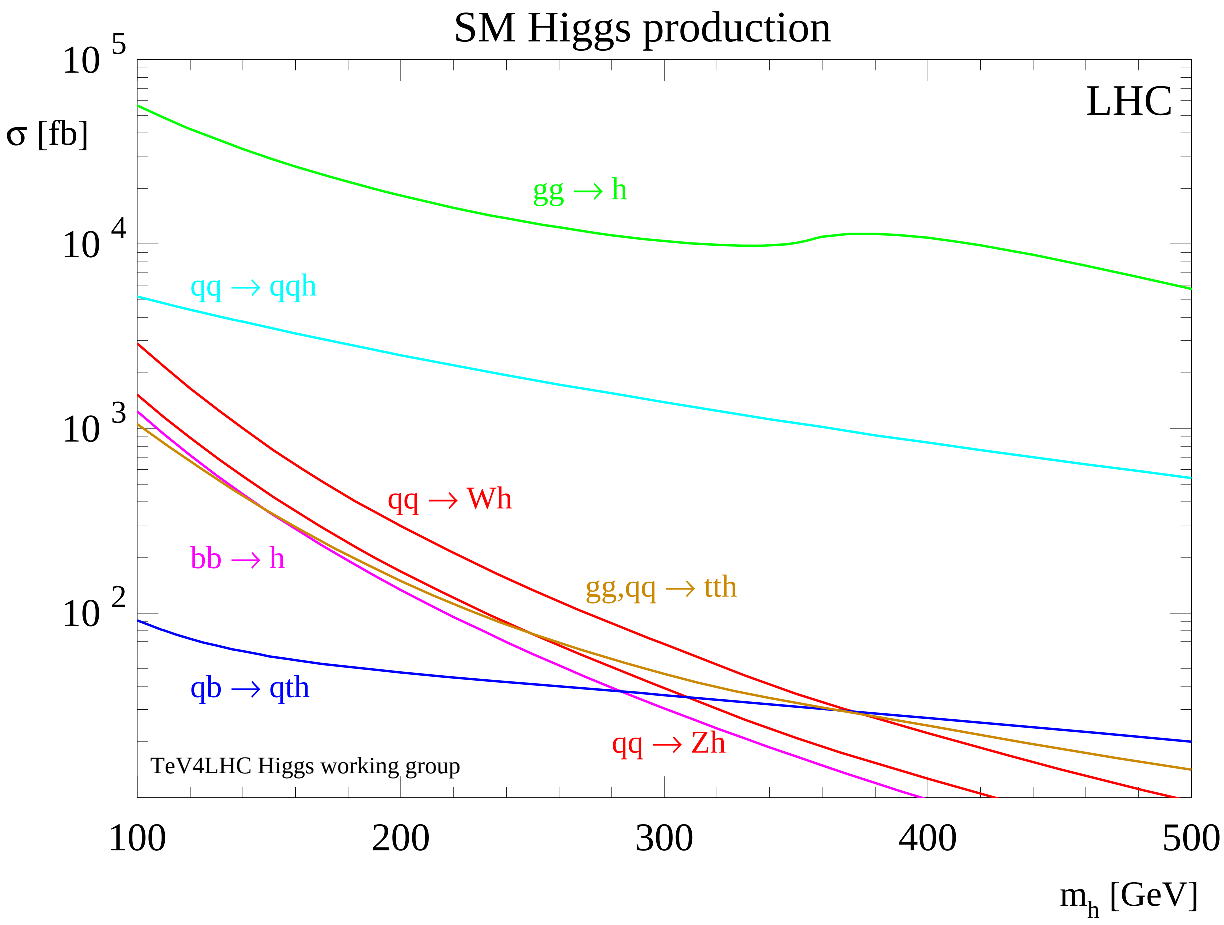
$$gg \to h_{SM} \to \gamma\gamma \quad , \quad gg \to h_{SM} \to VV^*$$

$$qq \to qqV^*V^* \to qqh_{SM} \quad , h_{SM} \to \gamma\gamma, \tau^+\tau^-, VV^*$$

$$gg, qq \to t\bar{t}h_{SM} \quad , \quad h_{SM} \to b\bar{b}, WW^*, WW^*$$

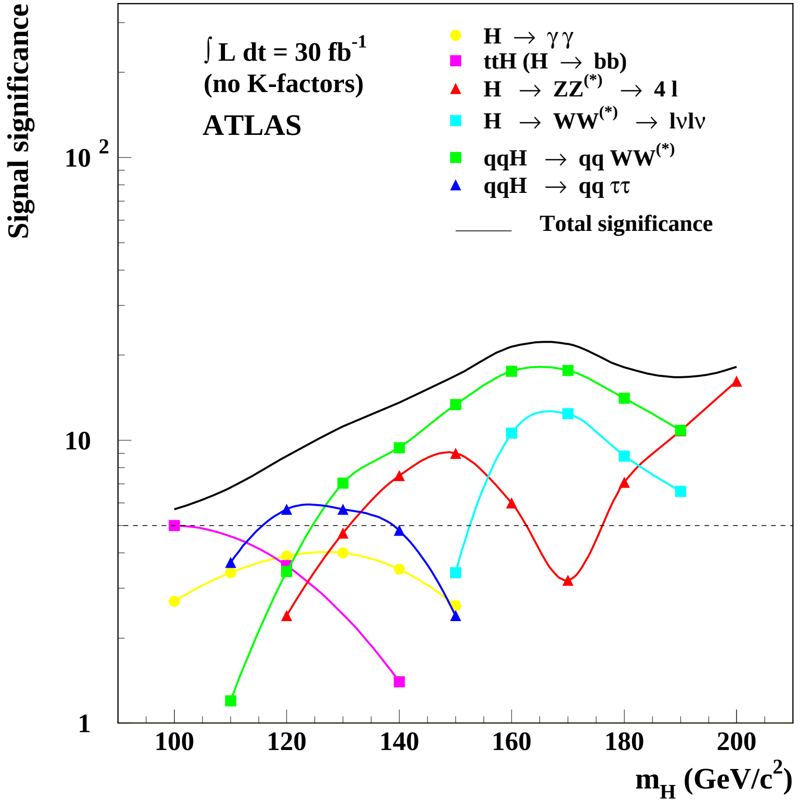
$$qq \to h_{SM}Z \ , \ qq' \to h_{SM}W \quad , \quad h_{SM} \to b\bar{b}(\text{Tevatron})$$

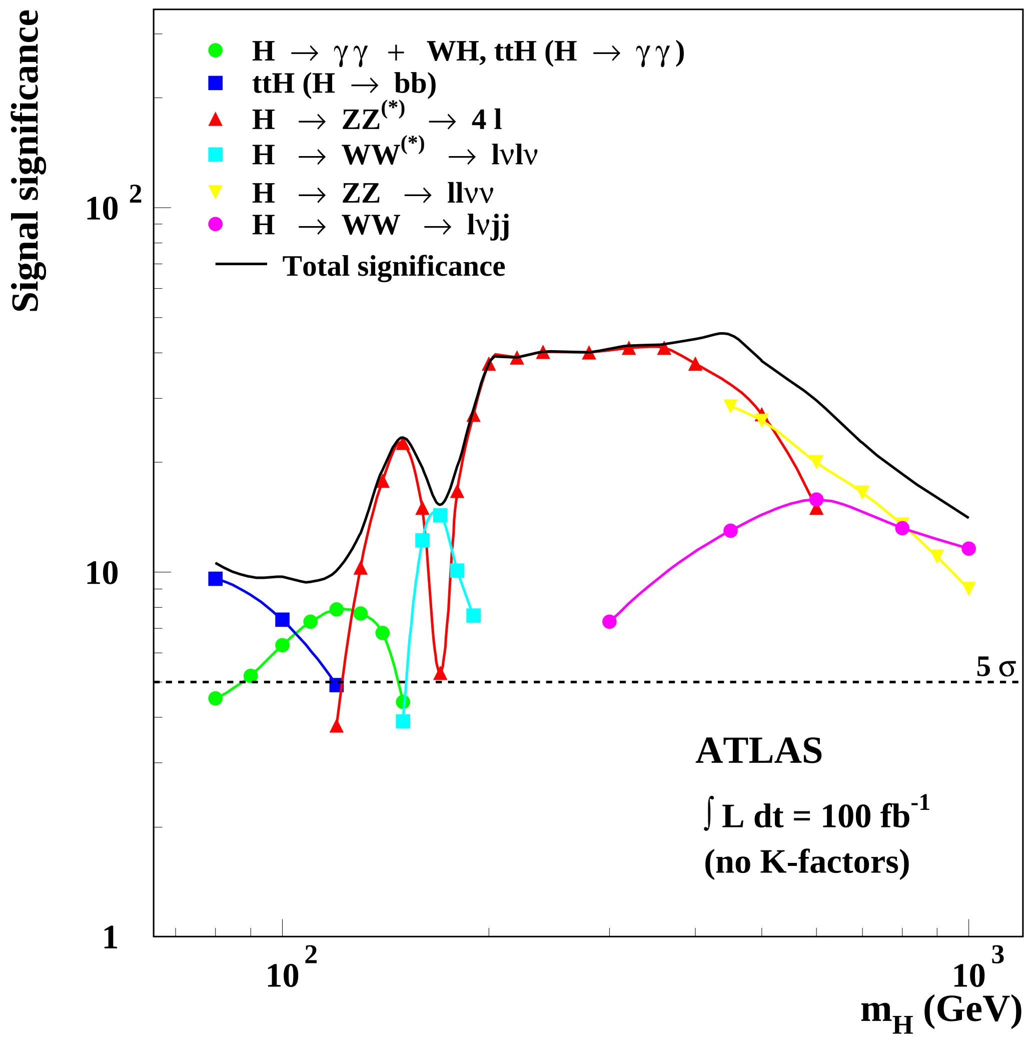
$$gg \to h_{SM}h_{SM}(doubleHiggsproduction)$$

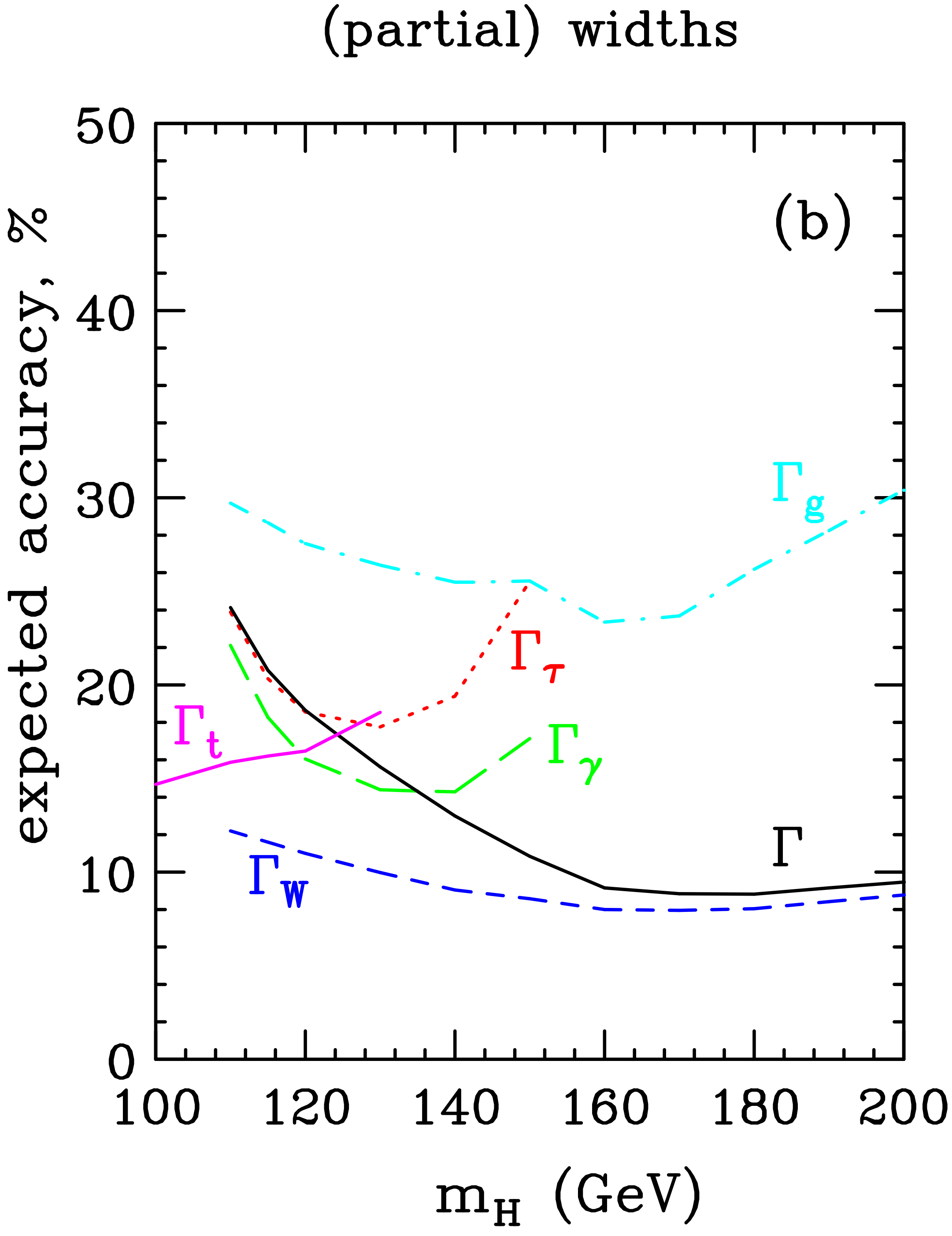

SM Higgs production
LHC
σ [fb]
10 5
10 4
10 3
10 2
gg → h
qq → qqh
qq → Wh
bb → h
gg,qq → tth
qb → qth
qq → Zh
TeV4LHC Higgs working group
100
200
300
400
500
m_h [GeV]

Significance for the experimental detection

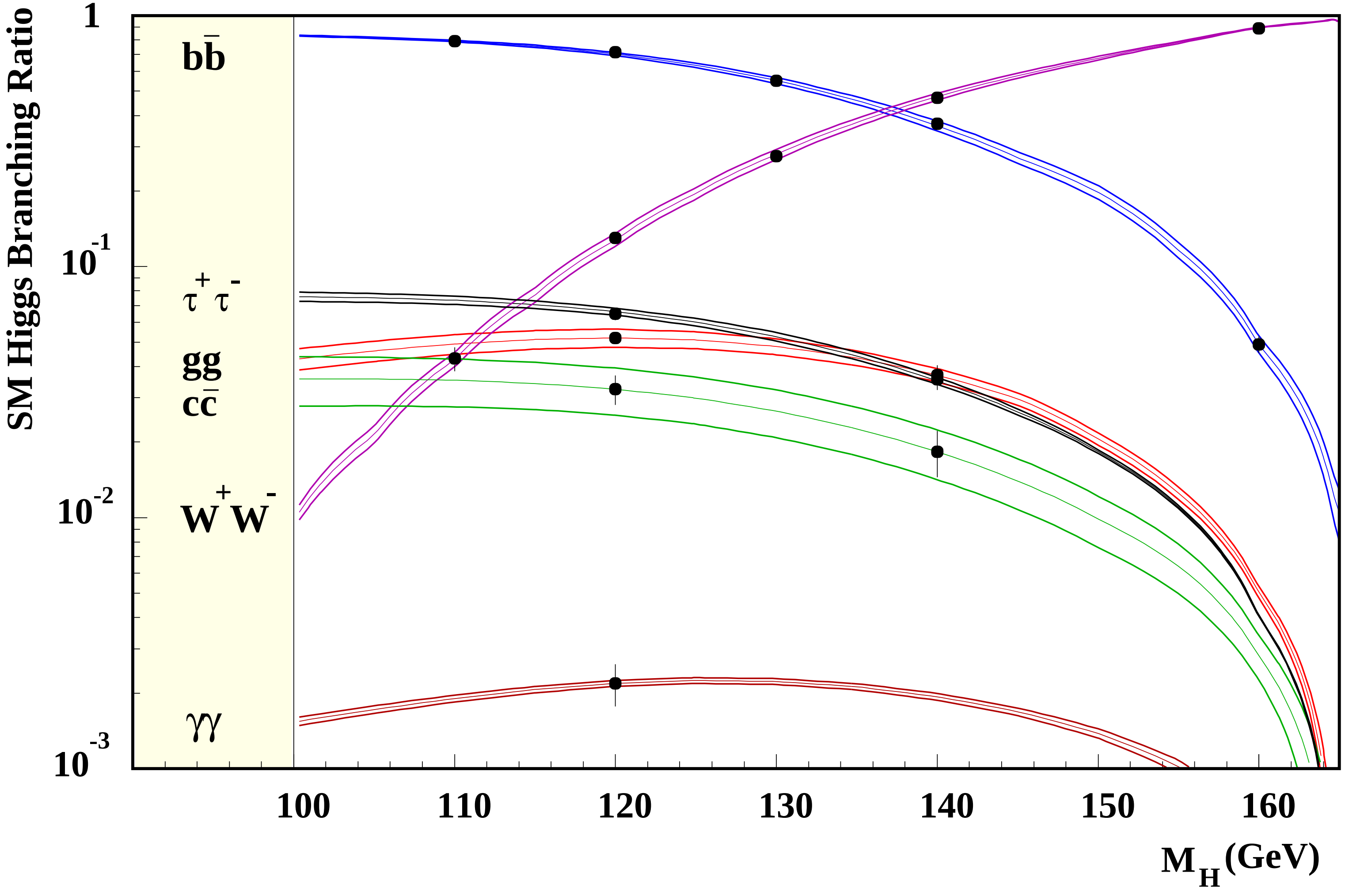
Low luminosity




Signal significance
10 2
10
1
10 2
10 3
m_H (GeV)
H → γγ + WH, ttH (H → γγ)
ttH (H → bb)
H → ZZ(*) → 4 l
H → WW(*) → lνlν
H → ZZ → llνν
H → WW → lνjj
Total significance
5 σ
ATLAS
∫ L dt = 100 fb-1
(no K-factors)


(partial) widths
(b)
expected accuracy, %
0
10
20
30
40
50
100
120
140
160
180
200
m_H (GeV)
Γ_g
Γ_τ
Γ_t
Γ_γ
Γ
Γ_W

At linear colliders (LC)Experimental accuracy



Extended Higgs sector

- With Extended Higgs sector: 2HDM Φ_1 , Φ_2, CP can be violated either explicitly or spontaneously in Higgs sector T.D.Lee'73
- Some models of dynamical electroweak symmetry breaking yields the 2HDM as their low-energy effective theory. [H. J. He et al, PRD**65**, (2002) hep-ph/0108041].
- Models for phase transition require 2 Higgs doublets
- Neutrino masses, Dark Matter, BAU
  Zee'80, Ma'06, Aoki, Kanemura, Seto'08

Coupling to fermions

- both Φ_1 and Φ_2 couple to fermions: $M_q = Y^u v_1 + Y^d v_2$: diagonalisation of M_q does not diagonalise similtanousely $Y^{u,d}$: FCNC at tree level: 2HDM-III
- 2HDM-I One doublet couple to gauge boson and the other one couple to fermion (like in SM).
- To avoid FCNC at tree level, We impose Z_2 symmetry (Weinberg Theorem): $\Phi_2 \to -\Phi_2$, $d_{iR} \to -d_{iR}$: 2HDM-II
- 2HDM-X or lepton-specific 2HDM (or Leptophilic Higgs): one doublet generates the masses of the charged leptons and the secon one generates the masses of the quarks
  Barnet, Senjanovic, Wolfenstein and Wyler'84

$$\begin{aligned} V \quad = \quad & \mu_1^2(\Phi_1^+\Phi_1) + \mu_2^2(\Phi_2^+\Phi_2) + \lambda_1(\Phi_1^+\Phi_1)^2 + \\ & \lambda_2(\Phi_1^+\Phi_1)^2 + \lambda_3(\Phi_1^+\Phi_1)(\Phi_2^+\Phi_2) + \lambda_4|\Phi_1^+\Phi_2|^2 \\ & +\{m_{12}^2(\Phi_1^+\Phi_2) + h.c\} + [\lambda_5(\Phi_1^+\Phi_2)^2 + h.c] \end{aligned}$$

- One can have: Explicit $\not{C}\!P$ if $\Im(m_{12}^4\lambda_5^*) \neq 0$;
- One can have Spontaneous $\not{C}\!P$ if: $|\frac{m_{12}^2}{\lambda_5 v_1 v_2}| < 1$; $< \Phi_1 >= v_1$, $< \Phi_2 >= v_2 e^{i\theta}$
- Five physical scalars (8 d.o.f=5+3): a charged Higgs pair $H^\pm$, two CP-evenh^0, H^0 and one CP-odd A^0
- 10 parameters $(\lambda_i)_{i=1,\ldots,5}$, μ_1^2, μ_2^2, m_{12}^2, v_1, v_2 with $v_1^2 + v_2^2 = (2\sqrt{2}G_F)^{-1}$ and 2 minimization conditions, We are left with 7 parameters.
- m_A, m_h, m_H, $m_{H\pm}$, α, $\tan\beta = v_1/v_2$ and m_{12}^2 free parameters.

Constraints on 2HDM parameters

Experimentals:

- Charged Higgs: $e^+e^- \to (\gamma^*, Z^*) \to H^+H^-$ at LEPII followed by $H^+ \to (\tau\nu_\tau\ ,\ c\bar{s})$; $M_{H^\pm} > 78.7$ GeV:.

This limit apply to all models in which BR($H^\pm \to \tau\nu_\tau$)+ BR($H^\pm \to cs$)=1.[L3: hep-ex/0309056, Delphi: hep-ex/0404012.]

- Neutral Higgs bosons: From $e^+e^- \to h^0A^0$ at LEPII, OPAL collaboration has put a limit on h^0 and A^0 masses of the 2HDM assuming 100% decays of h^0 and A^0 into hadrons.

$1 \lesssim M_h \lesssim 55$ GeV and $3 \lesssim M_A \lesssim 63$ GeV is excluded at 95% CL independent of α and $\tan\beta$. [Opal Collab hep-ex/0408097]

Theoretical constraints:

- $b \to s\gamma$: $m_{H^\pm} > 295$ GeV, $\forall \tan\beta$ in 2HDM-II. No such bound in 2HDM-I [P.Gambino et al, '01,F.Borzumati et al '98].
  In 2HDM-X, light $H^\pm$ is allowed Aoiki, H.Logan'09
- $\delta\rho \leq 10^{-3}$ [(PDG)]: constrain the splitting M_A and $M_{H^\pm}$
- Perturbativity on $\tan\beta$: $0.1 \leq \tan\beta \leq 70$ [V.D.Barger '90]
- Perturbativity on λ_i: $|\lambda_i| \leq 8\pi$
- Potential bounded from bellow: $\lambda_{1,2} > 0$, $\sqrt{\lambda_1\lambda_2} \geq \lambda_3 + \lambda_4 + \lambda_5$
- Unitarity constraints: in 2HDM there is 14 constraints coming from different channel:W^+W^-, ZZ, hh, HH, hH, AA, hA, H^+H^-, hH^+... [A.Akeroyd, A.A and E.Naimi PLB'2000, A.A '2000]

The decoupling limit of 2HDM

$M_{12}^2 \to \infty$, $\cos(\alpha-\beta) \to 0$

- In this limit, the masses of Φ=H, $H^\pm$, A:

$$m_\Phi^2 = M_{12}^2 + \sum_i \lambda_i v^2 + \mathcal{O}(v^4/M_{12}^2), \quad , \quad m_h^2 = \sum_i \lambda_i v^2$$

- When $M_{12}^2 \gg \lambda_i v^2$, $m^2_{H,A,H\pm}$ are determined by M_{12}^2, and are independent of λ_i. In this case $\alpha \to \beta - \pi/2$, The effective theory below M_{12} is described by one Higgs doublet. In this limit:

$$h^0VV/(h_{SM}VV) = \sin(\beta-\alpha) \to 1$$

$$h^0 b\bar{b}/h_{SM}b\bar{b} = -\frac{\sin\alpha}{\cos\beta} \to 1\ ,\ (h^0\bar{t}t)/h_{SM}t\bar{t} = \frac{\cos\alpha}{\sin\beta} \to 1$$

$$H^0VV \propto \cos(\beta-\alpha) \to 0\ ,\ (hhh)/(hhh)_{SM} \to 1$$

$$h^0H^+H^-, h^0A^0A^0, h^0H^0H^0, H^\pm t\bar{b}... \neq 0$$

Challenge of the decoupling limit

In case of extended Higgs sector like MSSM or 2HDM we have 4 physical Higgs: 2 CP even (h^0,H^0), 1 CP odd A^0 and a pair charged Higgs $H\pm$:

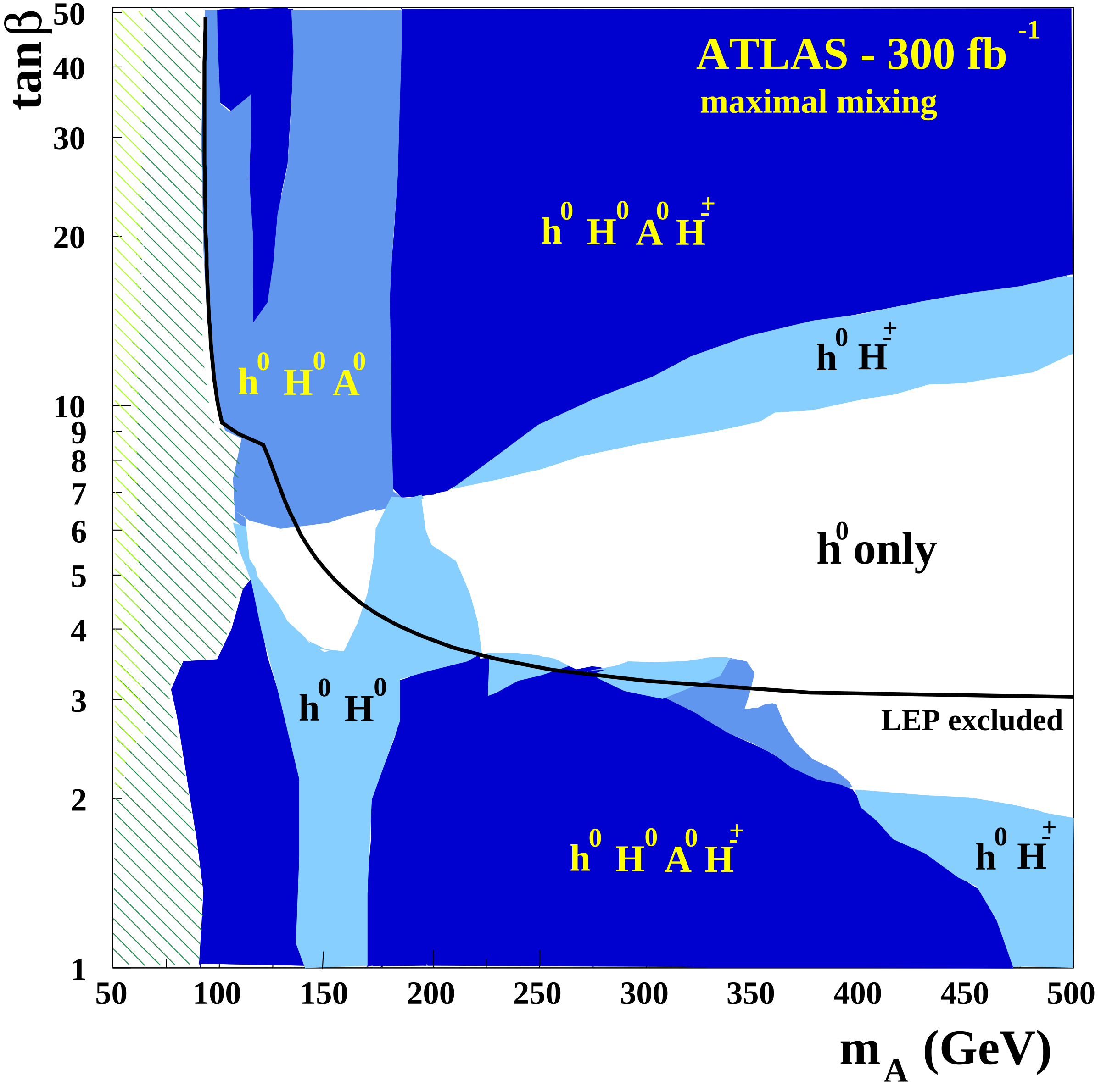
$$\sigma(\{pp, e^+e^-\} \to Z + h^0/H^0) = \sin^2/\cos^2(\beta-\alpha)\sigma_{SM}$$

$$\sigma(pp \to W + h^0/H^0) = \sin^2/\cos^2(\beta-\alpha)\sigma_{SM}$$

$$\sigma(e^+e^- \to A^0 + h^0/H^0) = \cos^2/\sin^2(\beta-\alpha)\lambda\sigma_{SM}$$

$$\sigma(\{pp, e^+e^-\} \to \nu\bar{\nu} + h^0/H^0)\sin^2/\cos^2(\beta-\alpha)\sigma_{SM}$$

$$\{gg, \gamma\gamma\} \to h^0\ ,\ H^0\ ,\ A^0$$


tanβ
50
40
30
20
10
9
8
7
6
5
4
3
2
1
50
100
150
200
250
300
350
400
450
500
m_A (GeV)
ATLAS - 300 fb^-1
maximal mixing
h^0 H^0 A^0 H^±
h^0 H^0 A^0
h^0 H^±
h^0 only
h^0 H^0
LEP excluded
h^0 H^0 A^0 H^±
h^0 H^±

A program of precision measurements will begin at LHC and will reach maturity at the ILC :

$$\delta(\Gamma_W)/\Gamma_W \approx 5 - 10\% \ , \ \delta(\Gamma_\tau)/\Gamma_\tau = \delta(\Gamma_\gamma)/\Gamma_\gamma \approx 18\% \text{ at LHC}$$

At Linear Collider(ILC), the situation is much better:

Relative accuracies (in %) on M_H and couplings at ILC $\sqrt{s} = 500$ GeV and $\int \mathcal{L} = 500$ fb^{-1} [hep-ph 0106315]

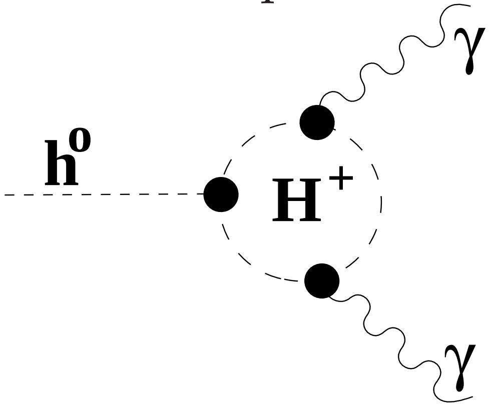
M_H	ΔM_H	g_{HWW}	g_{HZZ}	g_{Htt}	g_{Hbb}	$g_{H\tau\tau}$
120	±0.033	±1.2	±1.2	±3.0	±2.2	±3.3

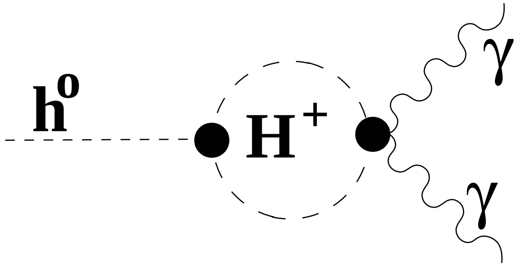
In $\gamma\gamma$ option of ILC: $\delta\Gamma(H \to \gamma\gamma)/\Gamma(H \to \gamma\gamma) \approx 2\%$ can be achieved (from $\gamma\gamma \to H \to b\bar{b}$).

Non decoupling effects in Higgs decays

A.A, W.Hollik and S.Penaranda PLB'04

- $h^0 \to \gamma\gamma$ is loop-mediated processes since the photon does not couple to neutral particles



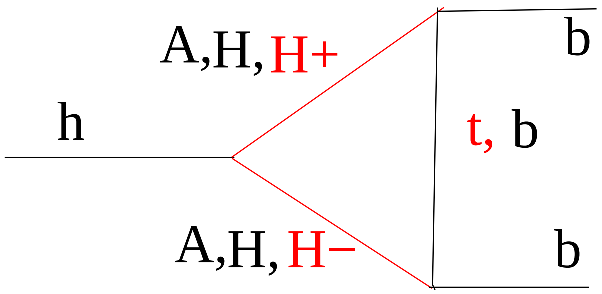


- The only pure 2HDM contribution comes from charged Higgs loops (if $\alpha = \beta - \pi/2$): $h^0 t\bar{t} \approx \frac{c_\alpha}{s_\beta} \approx 1 \ldots$

  $$g[h^0 H^+ H^-] \approx -\frac{g}{2M_W}\{M_{h^0}^2 + 2(M_{H^\pm}^2 - M_{12}^2)\}$$

  The decoupling is achieved when $M_{12} \to \infty$

- $h_0 \to b\bar{b}$, already exists at the tree level because of the Higgs–b Yukawa interaction
- Pure 2HDM one-loop contributions not present in the SM case:



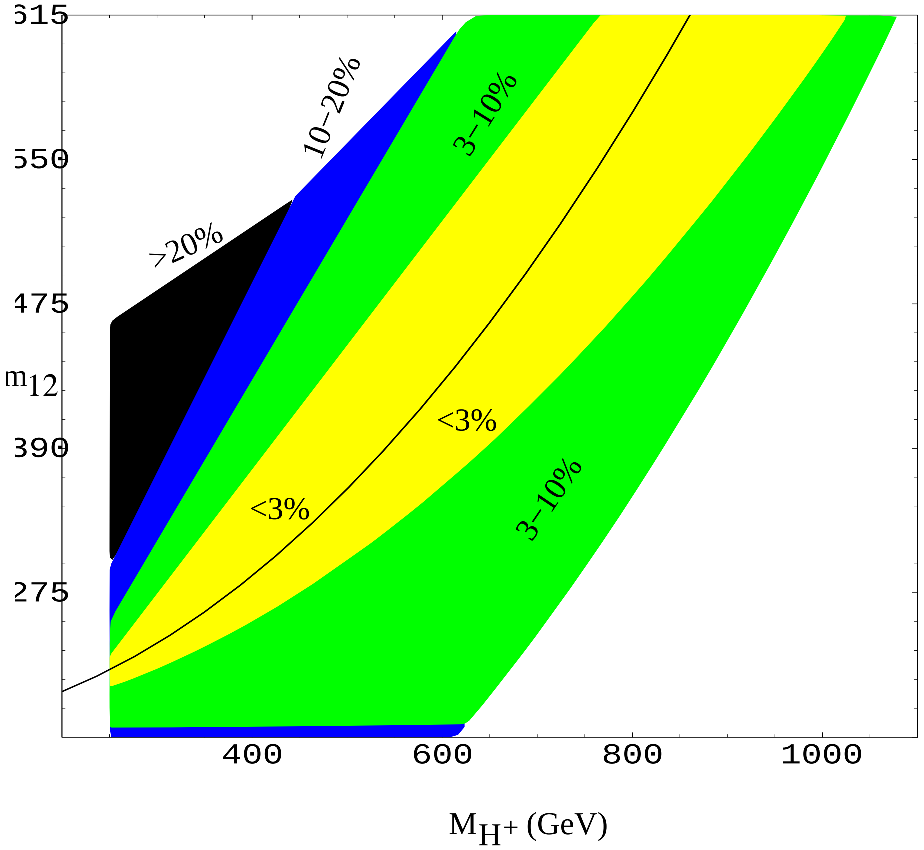
$\alpha \to \beta - \pi/2 \Rightarrow$ only $h^0H^+H^-$, $h^0H^0H^0$ and $h^0A^0A^0$ don't vanish or reduce to their SM values

$$\begin{aligned}
g[h^0H^+H^-] &\approx -\frac{g}{2M_W}\{M_{h^0}^2 + 2(M_{H^\pm}^2 - M_{12}^2)\}\\
g[h^0H^0H^0] &\approx -\frac{g}{2M_W}\{M_{h^0}^2 + 2(M_{H^0}^2 - M_{12}^2)\}\\
g[h^0A^0A^0] &\approx -\frac{g}{2M_W}\{M_{h^0}^2 + 2(M_{A^0}^2 - M_{12}^2)\}
\end{aligned}$$

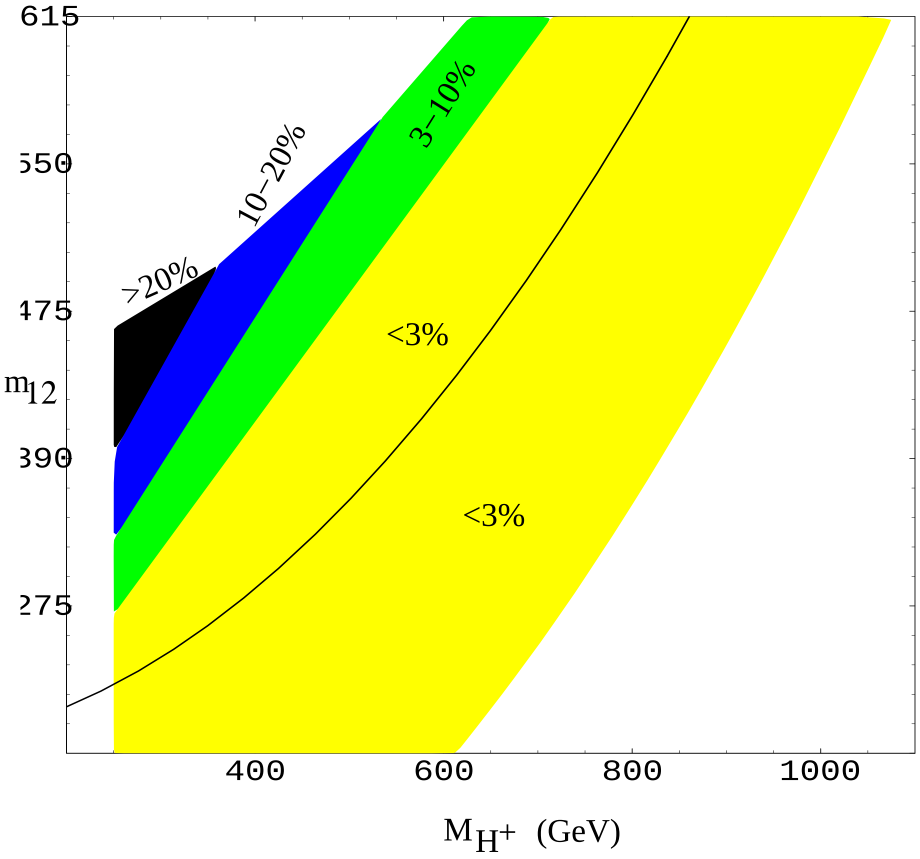
- $\Gamma_{\gamma\gamma}$ can be measured with 16% accuracy at ILC and Γ_{bb} with 2.2%.
- We want to distinguish 2HDM from SM in the decoupling regime: $(m_{A^0}, m_H, m_{H^\pm} \gg m_Z)$
- In the numerical evaluation we have parameterized the Higgs sector with:

$$M_{h^0} = 120\ GeV\ ,\ \ M_{H^0} = M_{A^0} = M_{H^\pm}\ ,\ \alpha \approx \beta - \pi/2\ ,\ \ M_{12}$$

$h^0 \to \gamma\gamma$: $\Delta_{\gamma\gamma} = |\frac{\Gamma(h\to\gamma\gamma)^{2HDM} - \Gamma(h\to\gamma\gamma)^{SM}}{\Gamma(h\to\gamma\gamma)^{SM}}|$



$h \to b\bar{b}$: $\Delta_{bb} = \left|\frac{\Gamma(h\to bb)^{2HDM} - \Gamma(h\to bb)^{SM}}{\Gamma(h\to bb)^{SM}}\right|$

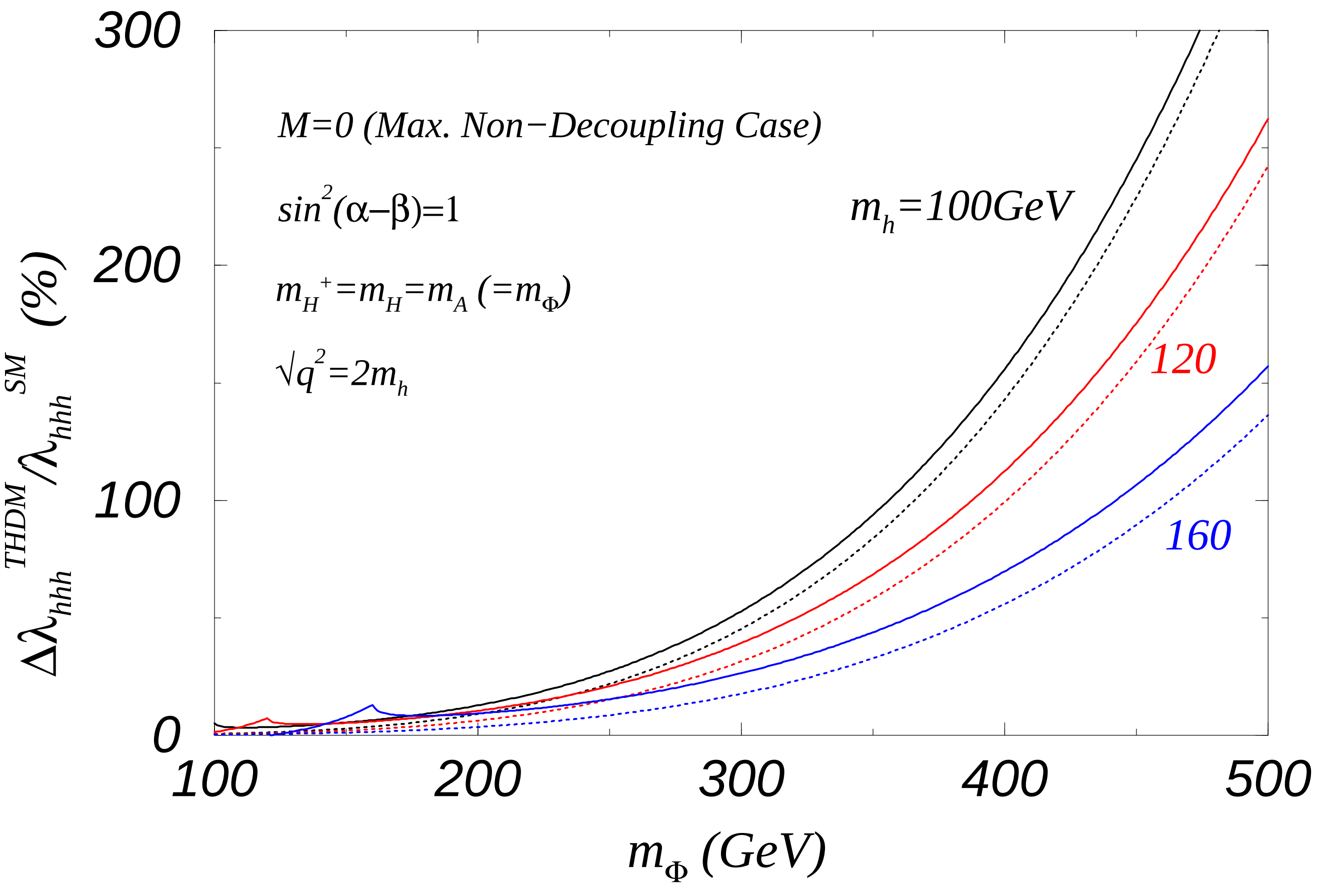


hhh^{eff} from S.Kanemura, E.Senaha, Y.Okada, C.P.Yuan PLB'02,

In the decoupling limit hhh^{eff} takes the following form

$$hhh_{eff} \quad = \quad \frac{3M_h^2}{v}\left\{1+\frac{m_\Phi^4}{3\pi^2 m_h^2 v^2}\left(1-\frac{m_{12}^2}{\sin^2\beta\cos^2\beta m_\Phi^2}\right)^3-\frac{N_{c_t}m_t^4}{3\pi^2 m_h^2 v^2}\right\},$$

with $m_\Phi = m_H = m_A = m_{H\pm}$.



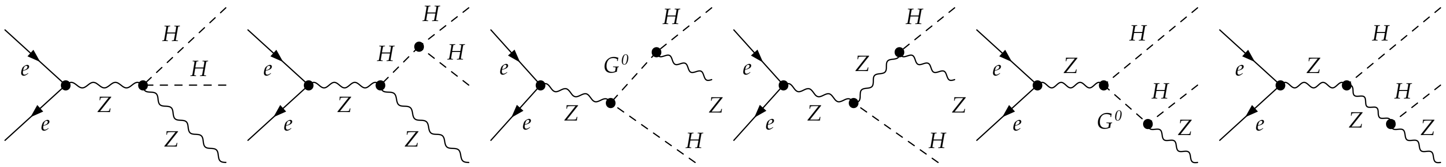
$\Delta\lambda_{hhh}^{THDM} \equiv \lambda_{hhh}^{eff}(THDM) - \lambda_{hhh}^{eff}(SM)$. The results of the full one-loop calculation are shown as solid curves.

1. Probing triple Higgs couplings in the 2HDM at e^+e^- collider

A.A, R.Benbrik and C.W. Chiang'08

- If the Higgs exist, it will be produced either at Tevatron-II or LHC.
- In order to establish the Higgs mechanism, we need to measure the Higgs couplings to fermions, to gauge boson as well as the self-interaction of Higgs bosons.
- Complementarity of LHC/ILC [G. Weiglein et al, "Physics interplay of the LHC and the ILC," Phys. Rept'06, hep-ph/0410364]
- SM scalar potential can be reconstructed by measuring the triple coupling λ_{hhh} and quartic coupling λ_{hhhh}.
- One can access to λ_{hhh} at ILC from $e^+e^- \to Zhh$

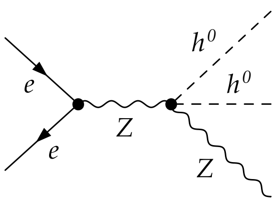
$e^+e^- \to Zhh$ in SM



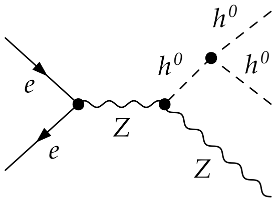
- In SM, $\sigma(e^+e^- \to Zhh)$ is rather small, for $\sqrt{s}, m_H = 500, 120$ GeV, $\sigma(e^+e^- \to Zhh) = 0.2$ fb

- possible to extract a signal from EW and QCD background $e^+e^- \to Zb\bar{b}b\bar{b}$ by simple kinematics cuts: e.g, invariant masses... Much more events are possible if: [D.Miller et al hep-ph/9906395]
  - Very high luminosity
  - Excellent b tagging
  - Beam polarization.

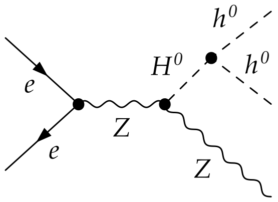
$e\ e \to h^0\ h^0\ Z$



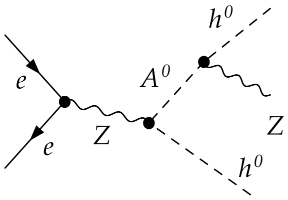
SM



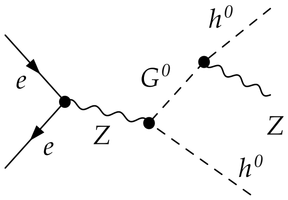
SM



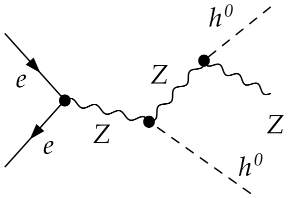
decouple



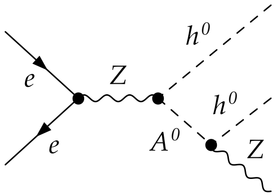
decouple



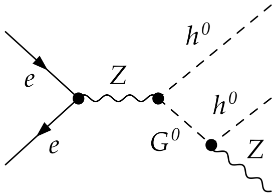
SM



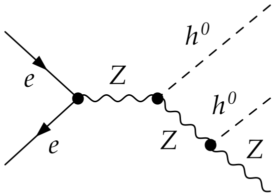
SM



decouple



SM



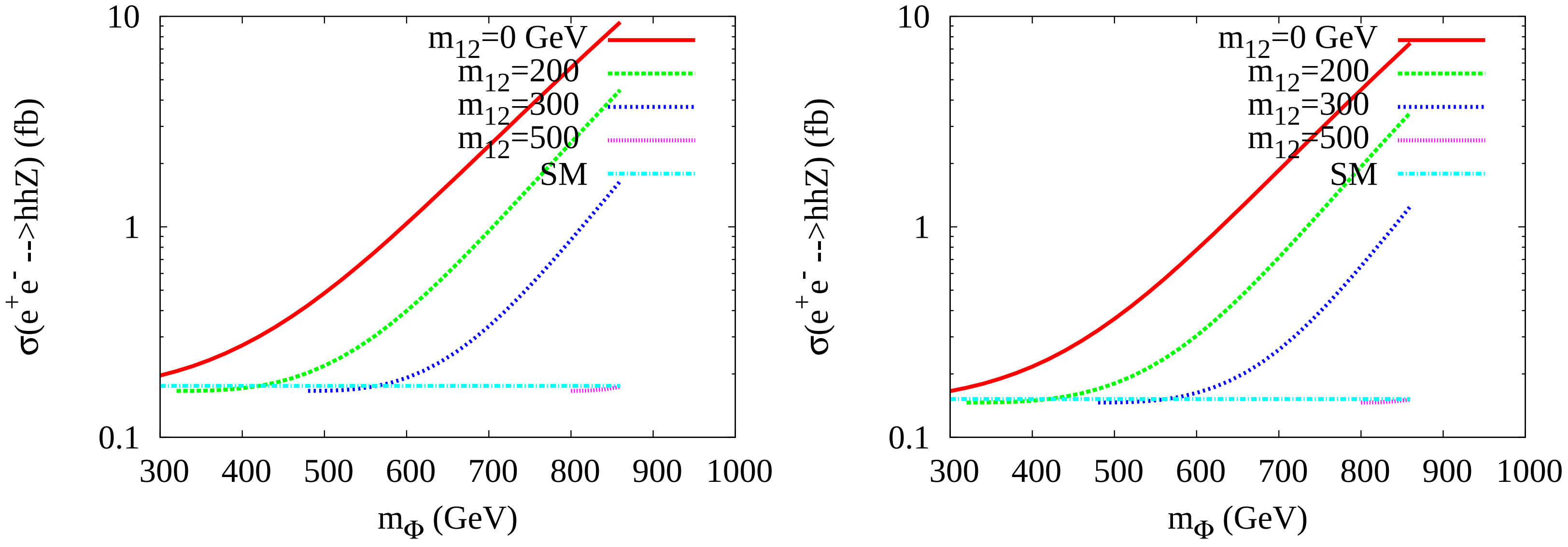
SM

In 2HDM we are sensitive to:

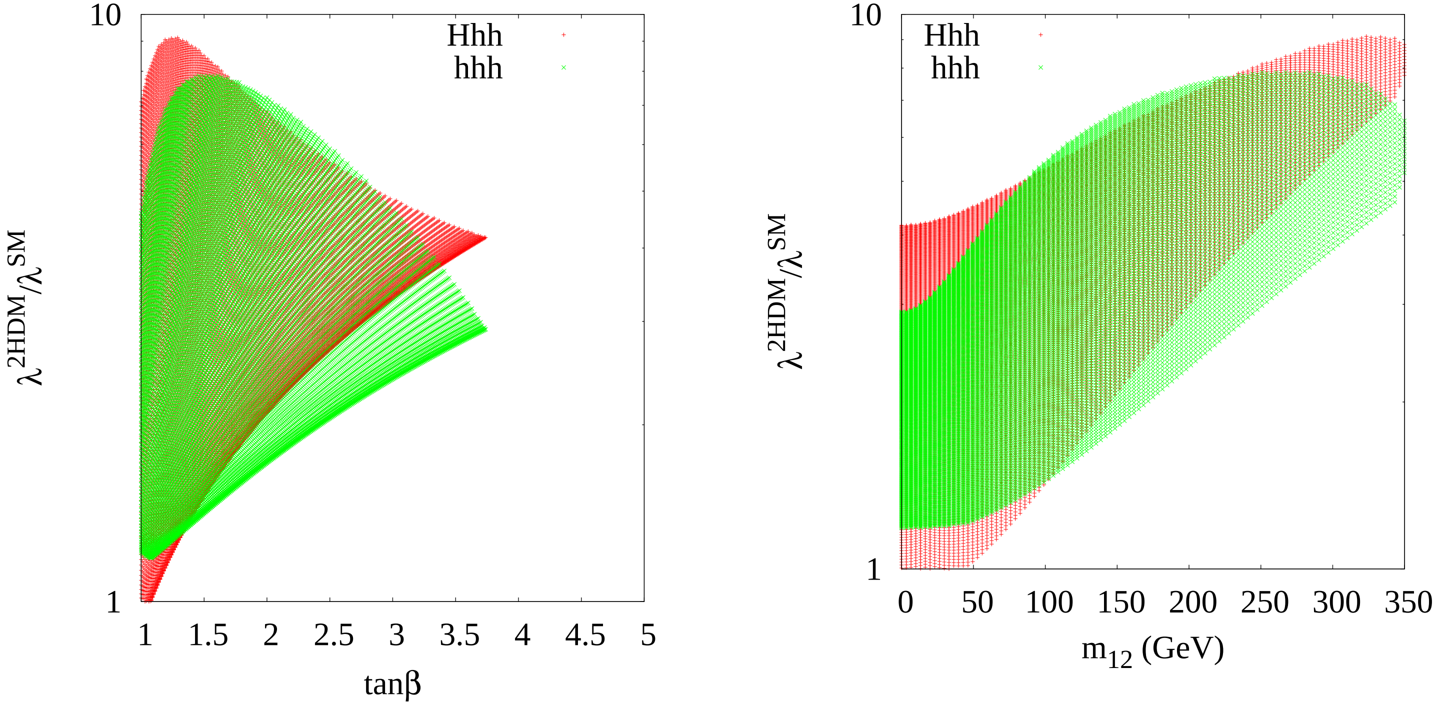
$$\begin{aligned} hhh &= \frac{-3e}{m_W s_W s_{2\beta}^2}\left[(c_\beta c_\alpha^3 - s_\beta s_\alpha^3) s_{2\beta} m_{h^0}^2 - c_{\beta-\alpha}^2 c_{\beta+\alpha} m_{12}^2\right] \\ Hhh &= -\frac{1}{2}\frac{e c_{\beta-\alpha}}{m_W s_W s_{2\beta}^2}\left[(2m_{h^0}^2 + m_{H^0}^2) s_{2\alpha} s_{2\beta} - (3s_{2\alpha} - s_{2\beta}) m_{12}^2\right] \end{aligned}$$

$e^+e^- \rightarrow Zhh$ in the decoupling limit: $m_\Phi = m_H = m_A = m_{H^\pm}$

$$hhh_{eff} \quad = \quad \frac{3M_h^2}{v}\left\{1+\frac{m_\Phi^4}{3\pi^2 m_h^2 v^2}\left(1-\frac{m_{12}^2}{\sin^2\beta\cos^2\beta m_\Phi^2}\right)^3 - \frac{N_{c_t} m_t^4}{3\pi^2 m_h^2 v^2}\right\},$$



$m_h = 120$ GeV, $\sqrt{s} = 500$ GeV (left) and $\sqrt{s} = 800$ GeV (right).
Away from decoupling limit one can reach 100 fb for $Z\Phi_i\Phi_j$.



$m_h, M_H, M_A, M_{H\pm} = 120, 300, 350, 300$ GeV, $\sin\alpha = -0.9$,
$1 \lesssim \tan\beta \lesssim 10$, $m_{12} \in [0, 600]$ GeV

$e^+e^- \to Z\Phi_i\Phi_j$

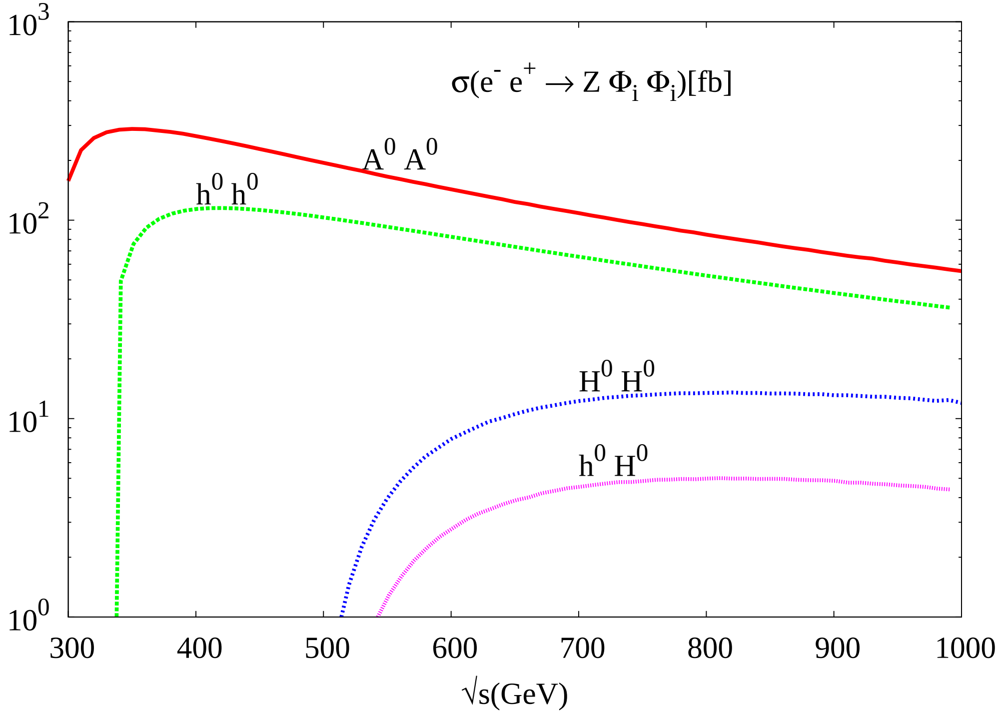
$m_{12} = 0,\ m_{H\pm} = 250$ GeV , $\tan\beta = 10$

Zhh, $m_{h,H,A} = 120, 240, 150$ GeV , $\sin\alpha = 0.8$

ZAA, $m_{h,H,A} = 120, 200, 100$ GeV , $\sin\alpha = 0.6$

ZHH , $m_{h,H,A} = 120, 140, 360$ GeV , $\sin\alpha = -0.1$

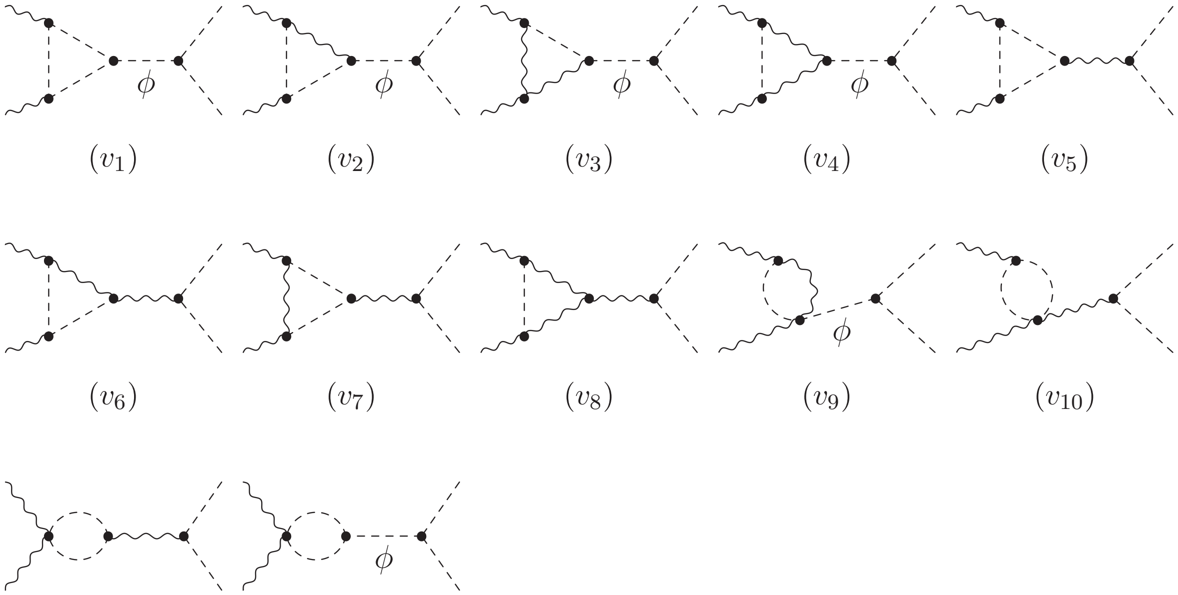
ZhH , $m_{h,H,A} = 120, 200, 300$ GeV , $\sin\alpha = -0.7$



Probing triple Higgs couplings in the 2HDM at $\gamma\gamma$ collider

A.A, R.Benbrik and C.H.Chen and R.Santos'09

- $\gamma\gamma \to hh$ is loop medited, then very sensitive to new physics.
- $\gamma\gamma \to hh$ has more phase space than $e^+e^- \to Zhh$



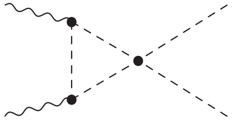
(v_1) (v_2) (v_3) (v_4) (v_5)

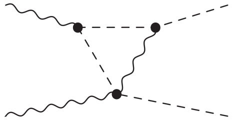
(v_6) (v_7) (v_8) (v_9) (v_{10})

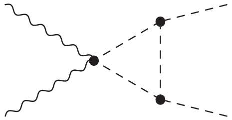
(v_{11}) (v_{12})

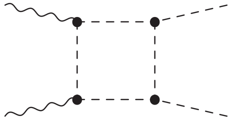
Just charged Higgs contribution are shown

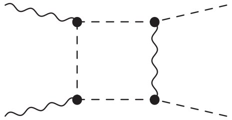
In 2HDM, scalar loops dominate

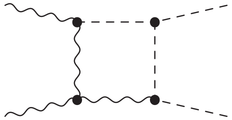

(b_1)


(b_2)


(b_3)


(b_4)


(b_5)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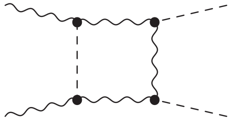
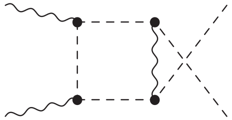

(b_7)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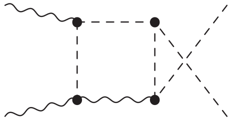
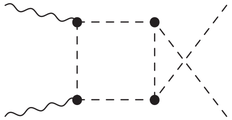
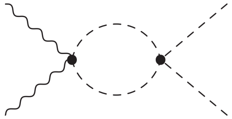
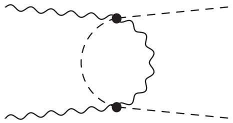
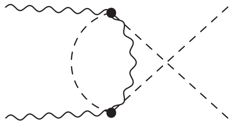

(b_9)


(b_{10})


(b_{11})


(b_{12})

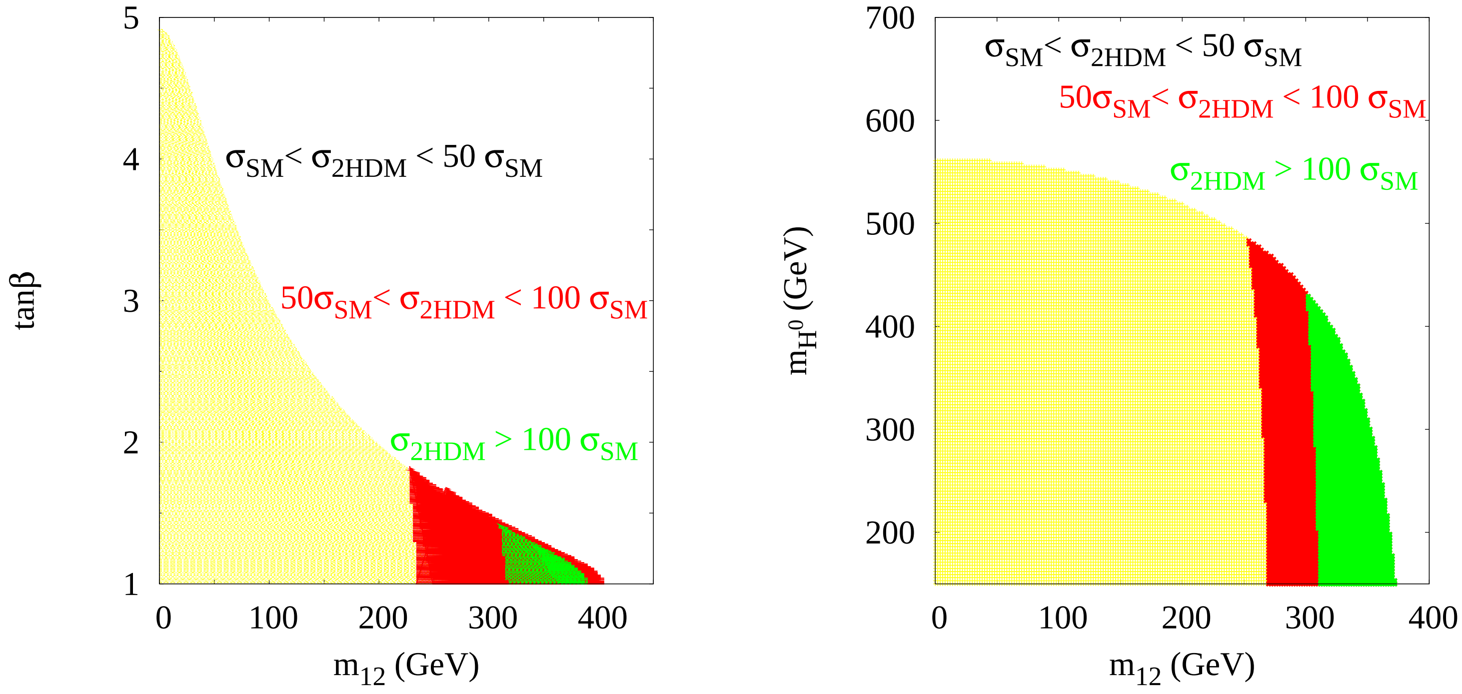

(b_{13})

www.FeynArts.de , FormCalc , LoopTools, (T.Hahn)

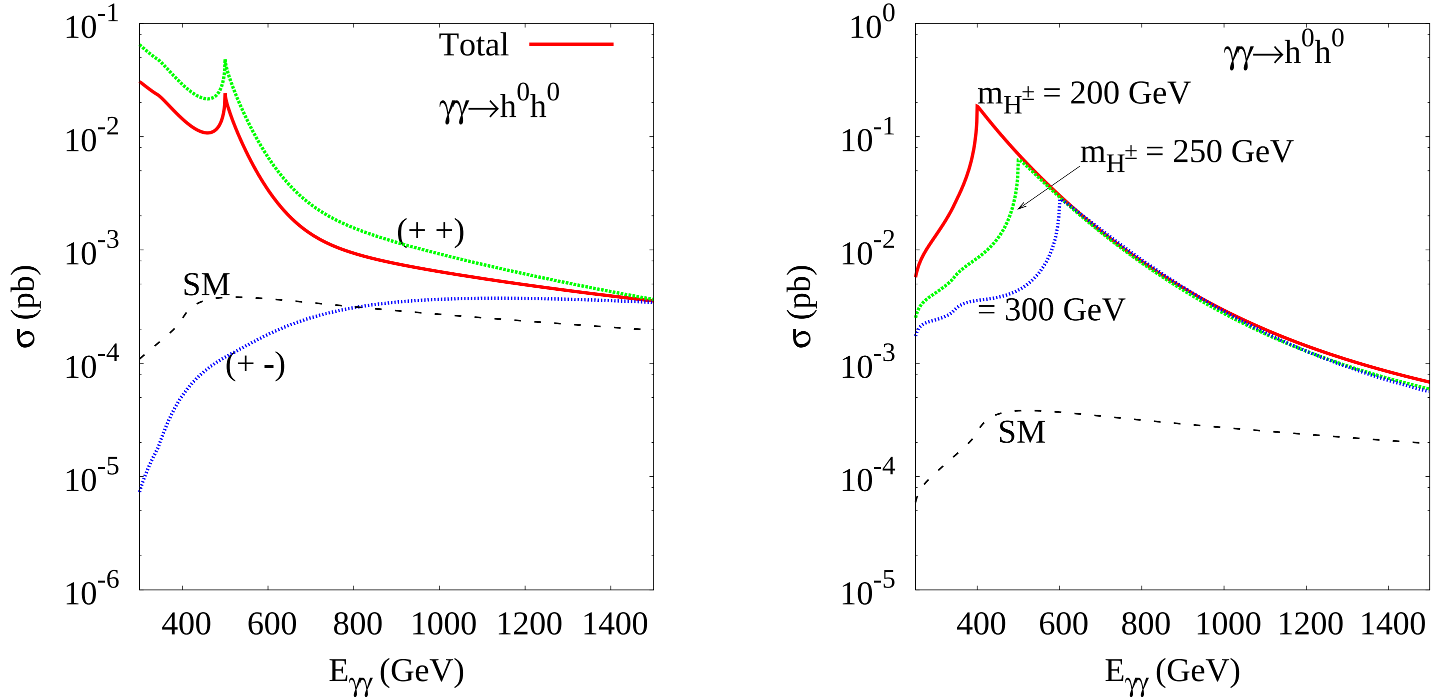
$\gamma\gamma \to HH$ in SM

Jikia'92, Belusevic'04 and Takahashi'08

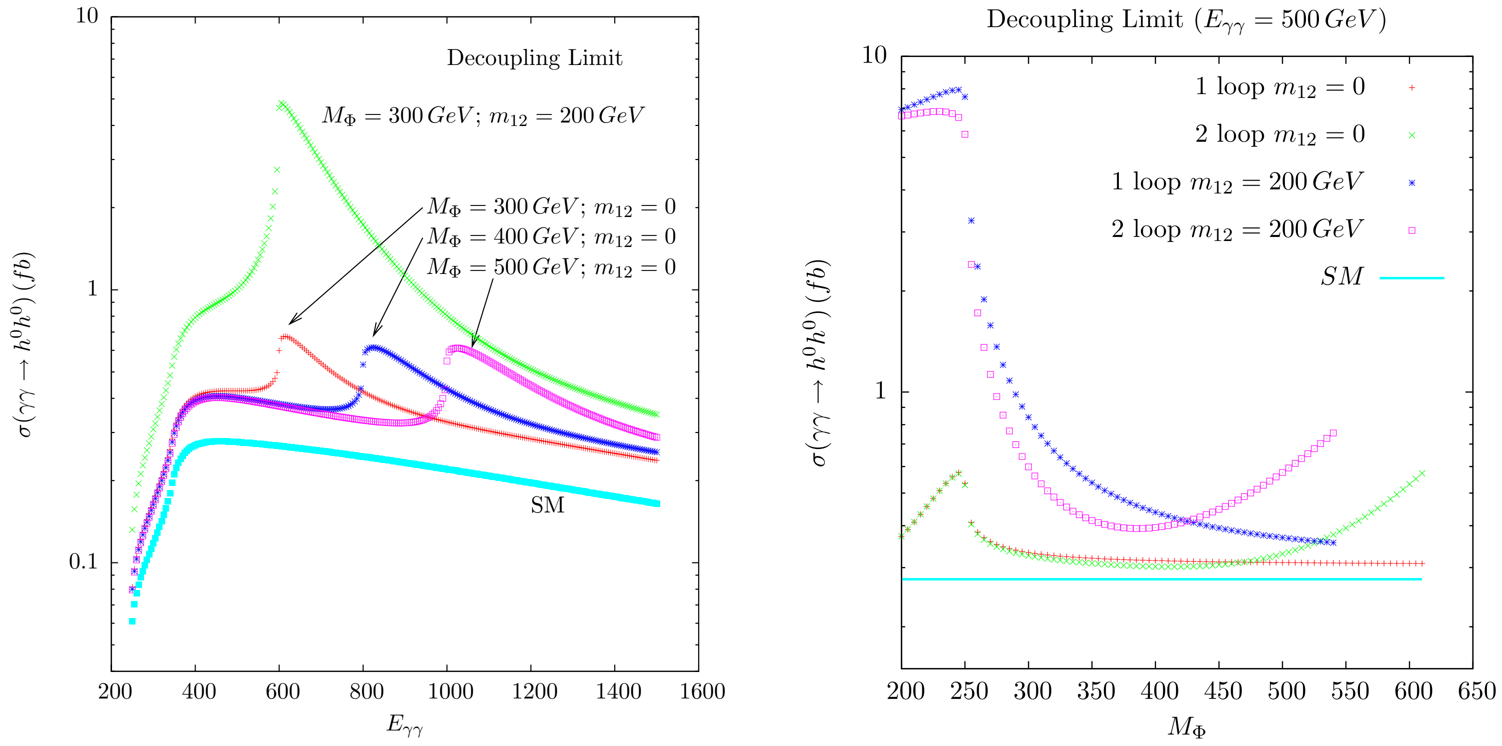
- look for $\gamma\gamma \to HH \to 4b$
- Main background from W^+W^- and from non-resonant four jet final state.
- Select 2 jet and reconstruct Higgs mass, $M(q\bar{q} - MH) < 5$ GeV
- Conclusion: For a center of mass energy of 350 GeV and $m_H = 120$ GeV an integrated luminosity of 450 fb^{-1} would be needed to exclude a zero Higgs boson self-coupling at the 5 σ level.



$m_{h^0} = 115$ GeV, $m_{A^0} = 270$ GeV , $m_{H^\pm} = 350$ GeV.
Left $m_{H^0} = 2m_{h^0}$, $E_{\gamma\gamma} = 500$ GeV, $-1 \le \sin\alpha \le 1$, $1 \lesssim \tan\beta \lesssim 10$
and right $\tan\beta = 1$, $\sin\alpha = -0.9$, $E_{\gamma\gamma} = 800$ GeV


10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
σ (pb)
Total
γγ→h^0h^0
(+ +)
SM
(+ -)
400
600
800
1000
1200
1400
E_γγ (GeV)
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
σ (pb)
γγ→h^0h^0
m_H± = 200 GeV
m_H± = 250 GeV
= 300 GeV
SM
400
600
800
1000
1200
1400
E_γγ (GeV)

Decoupling limit, $m_h = 120$ GeV

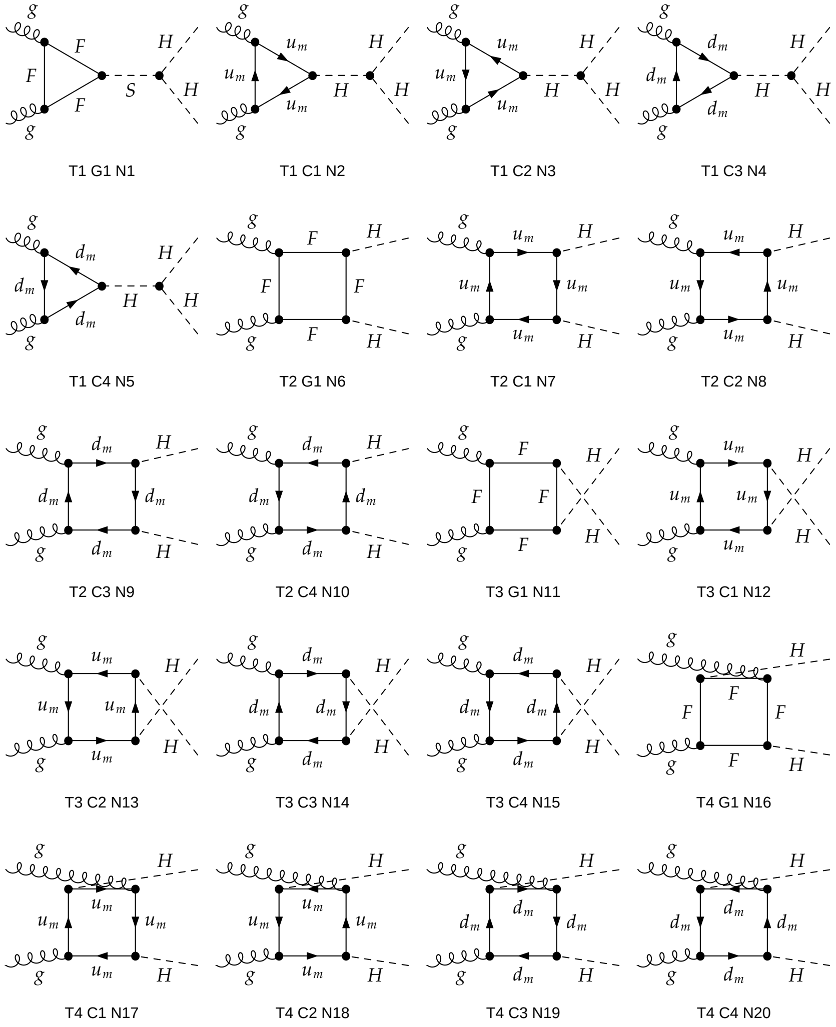


(Left) $\gamma\gamma \to hh$ at LO,

(Right) $\gamma\gamma \to hh$ at LO and LO + High order corrections to hhh

3. Probing triple Higgs couplings in the 2HDM at LHC

(A.A, R.Benbrik, C.H. Chen, R. Guedes and R.Santos'09)

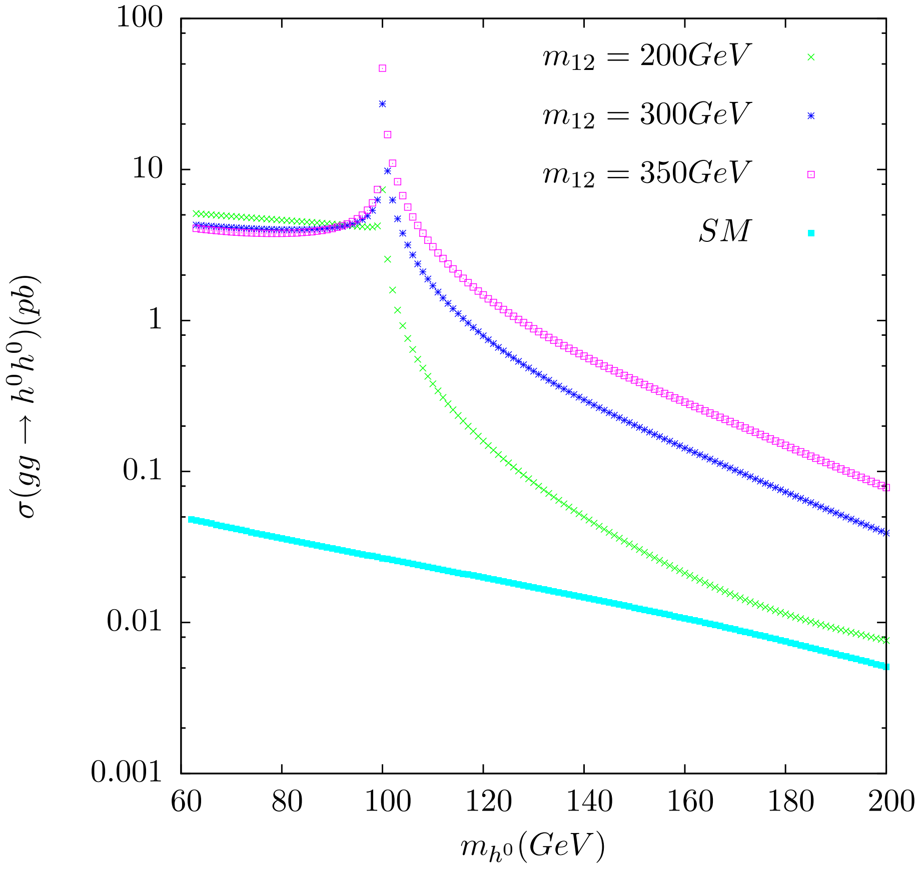


- In SM, the cross section is small $1 \lesssim \sigma(gg \to HH) \lesssim 3$ fb for $120 \lesssim M_H \lesssim 190$ GeV.

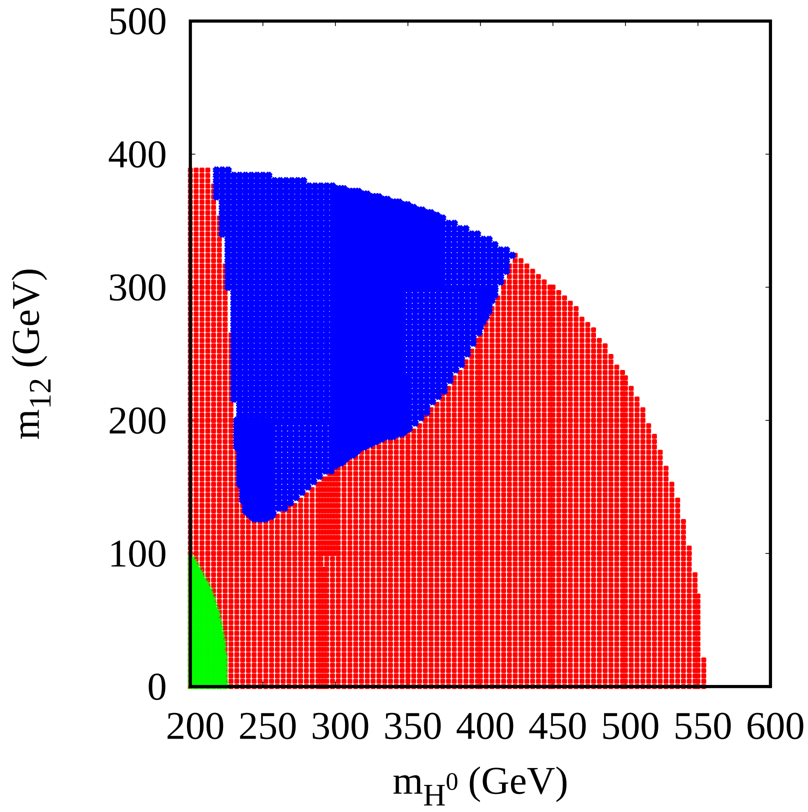
- $150 \lesssim M_H \lesssim 200$ GeV, from $gg \to HH \to W^+W^-W^+W^- \to 2l4j$ or $3l2j$, the non vanishing of the triple Higgs coupling of the SM can be established at 95% CL (with 300 fb^{-1}).

- One need VLHC to measure the triple Higgs coupling of the SM with an accuracy of 8-25% at 95% CL.U. Baur et al '03

- $M_H \lesssim 140$ GeV, $gg \to HH \to b\bar{b}\gamma\gamma$, look promising. With 600 fb^{-1} or more, we could make a rough first measurement for $M_H = 120$ GeV (with 6 signal events). U. Baur et al '04

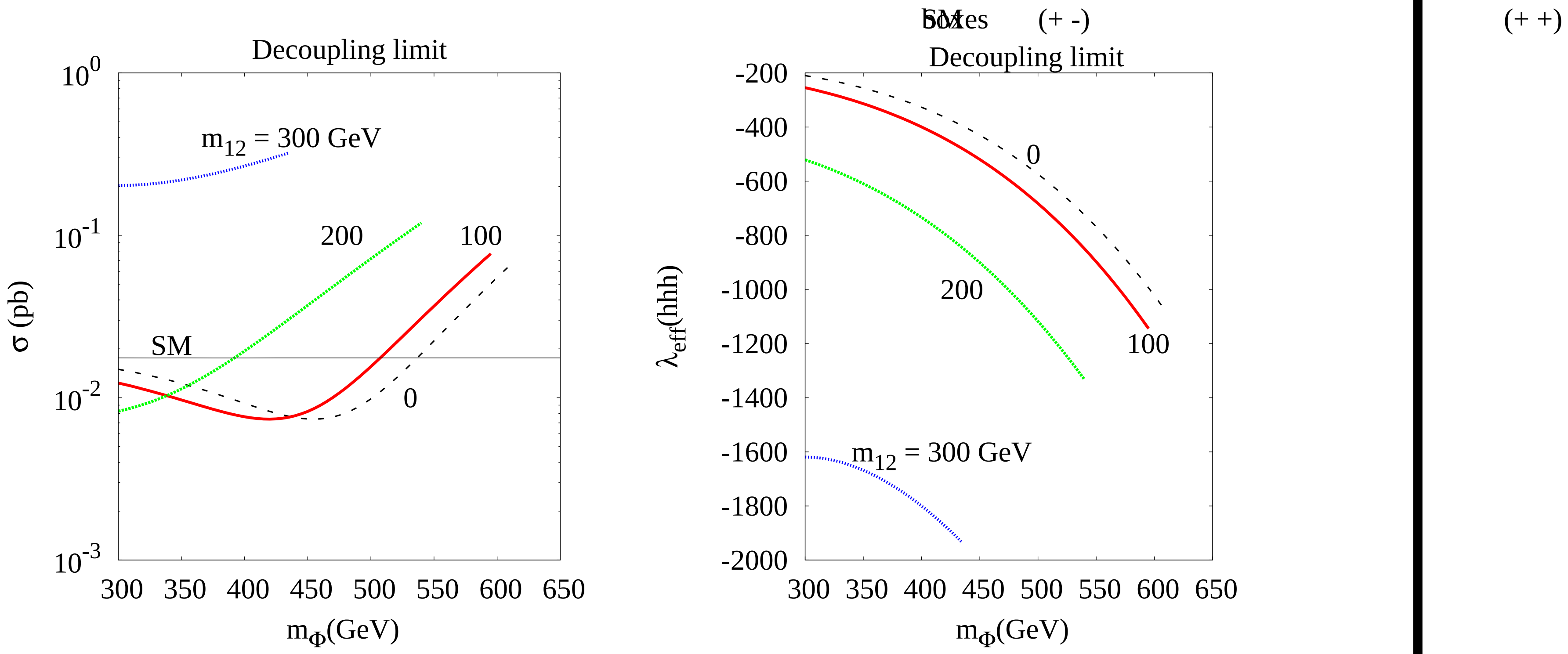


$m_{H^0} = 200GeV$, $m_A = 200GeV$, $m_{H^\pm} = 300GeV$, $\sin\alpha = 0.631$ and $\tan\beta = 1$. $(\sin(\beta - \alpha) = 0.1)$

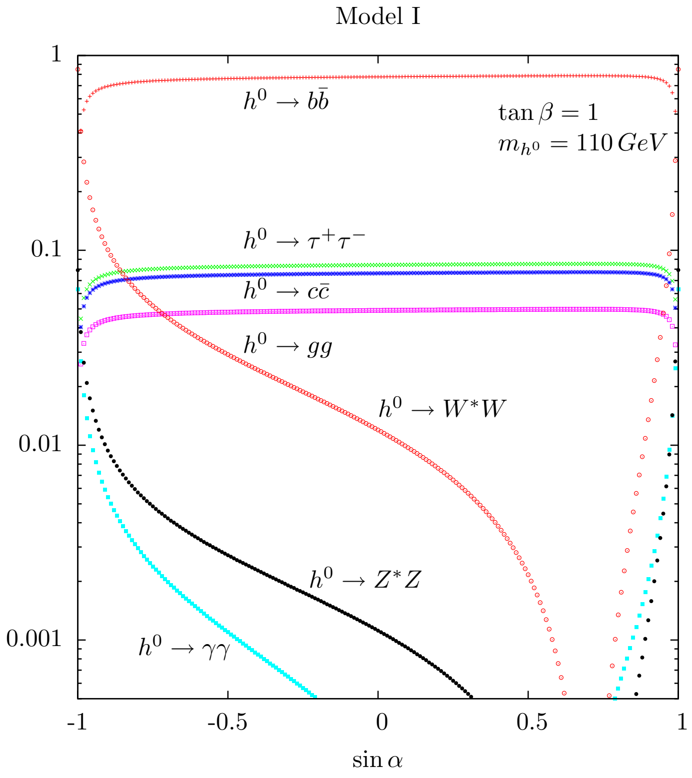


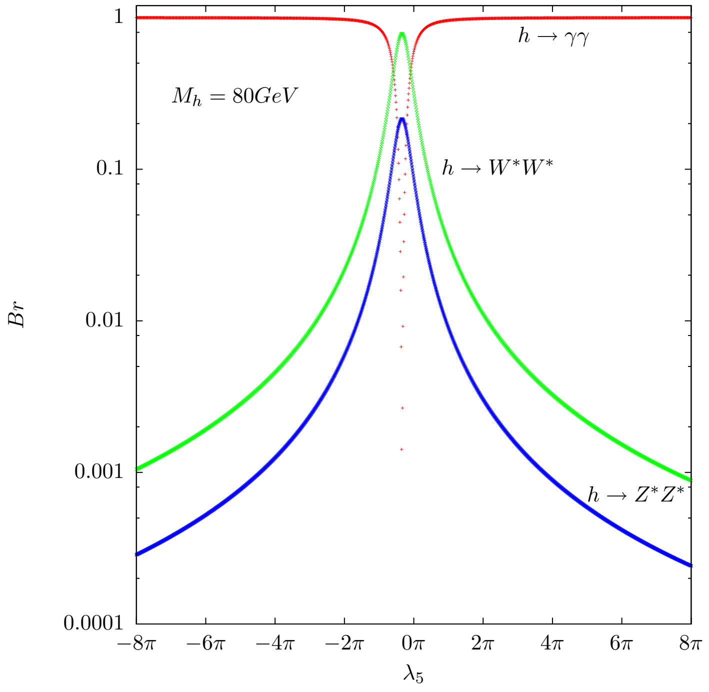
$m_h = 115$, $m_{H\pm} = 300$, $m_A = 100$ GeV $\sin\alpha = -0.9$, $\tan\beta = 1$,
$200 \lesssim m_H \lesssim 600$ GeV, $0 \lesssim m_{12} \lesssim 400$ GeV.

$\sigma_{2HDM} < \sigma_{SM}$, $\sigma_{2HDM} > 100\sigma_{SM}$, $\sigma_{SM} \lesssim \sigma_{2HDM} < 100\sigma_{SM}$,

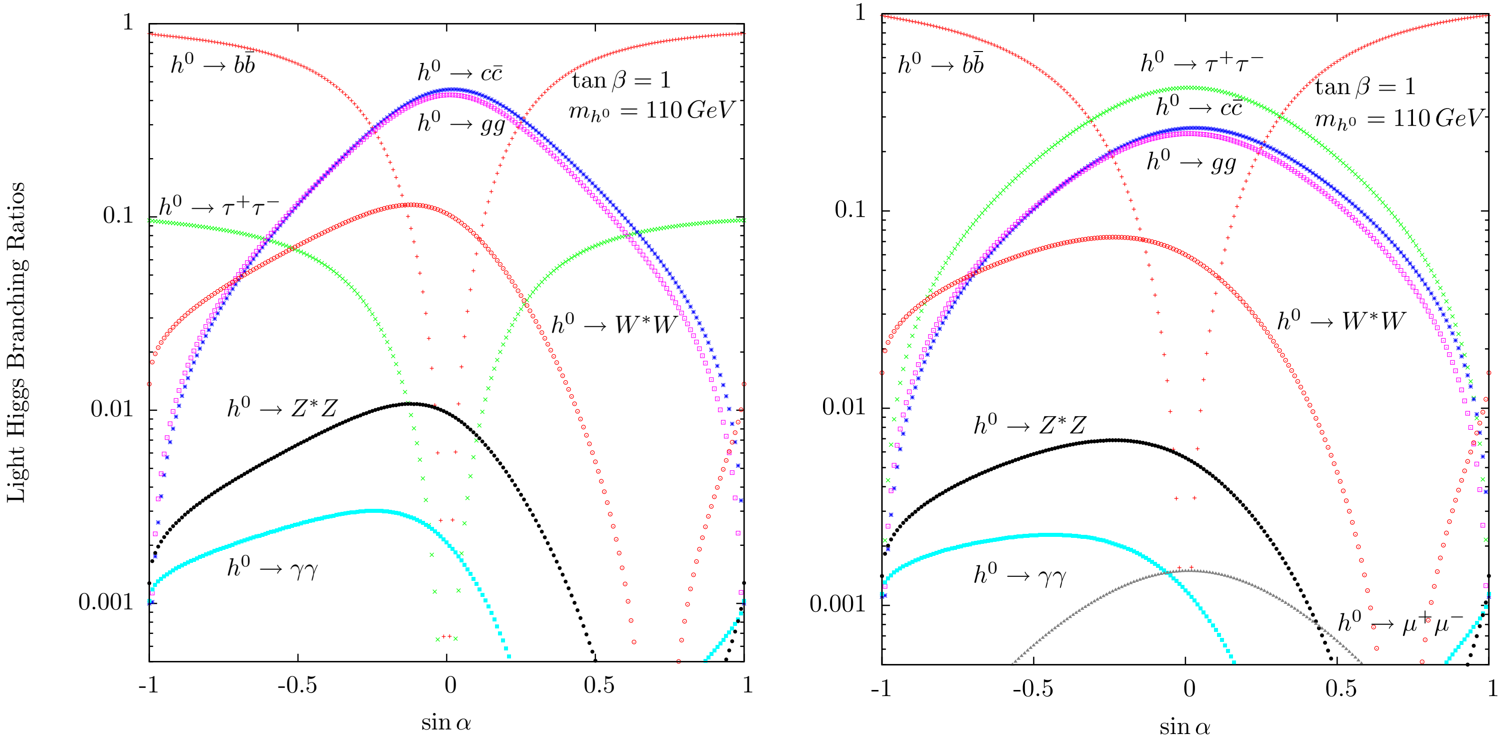

Decoupling limit
10^0
10^{-1}
10^{-2}
10^{-3}
σ (pb)
m_{12} = 300 GeV
200
100
SM
0
300
350
400
450
500
550
600
650
m_Φ(GeV)
SM
boxes
(+ -)
(+ +)
Decoupling limit
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
-2000
λ_{eff}(hhh)
0
200
100
m_{12} = 300 GeV
300
350
400
450
500
550
600
650
m_Φ(GeV)

Higgs signatures





Higgs signatures



Left: 2HDM-II , Right 2HDM-X (leptophilic Higgs)

Conclusions

- LHC will be capable to discover the Higgs bosons and measure its coupling to top quark, τ lepton, W and Z with 10–30% accuracy ($\mathcal{L} = 300 fb^{-1}$).
- At LC, the precision of the measurement is about 1–2%, such precision is needed to distinguish between models.
- In 2HDM, non decoupling effects could be large to be measured both at LHC and ILC and its $\gamma\gamma$ option.
- If 2HDM Higgs masses are not too heavy, their triple self couplings can be accessible at LHC and ILC