CP violating Two Higgs Doublet Model

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- Natural 2HDM II ($\mathcal{L}_{\mathcal{H}}$: $\lambda_6 = \lambda_7 = 0$ and $|m_{12}^2|/v^2 \ll 1$ & $\mathcal{L}_{\mathcal{Y}}$: Model II)
- SM-like scenarios (CP consv.): $|\chi_V| = |\chi_u| = |\chi_d| = 1$
  - $\gamma\gamma h(H)$ (non-decoupling of H^+)
  - $ggh(H)$
- "SM-like" h ($\sim h_1$) and HA mixing: for $h_2 \to WW/ZZ$
  - full simulation for Photon Linear Collider (PLC)
  - synergy LHC-LC-PLC

2HDM models without and with CP violation

I. Ginzburg, M. Krawczyk, P. Osland hep-ph/0101208, hep-ph/0101229,hep-ph/0211371

2HDM Potential with quartic and quadratic terms separated:

$$
\begin{aligned}
V = & \frac{1}{2}\lambda_1(\phi_1^\dagger\phi_1)^2 + \frac{1}{2}\lambda_2(\phi_2^\dagger\phi_2)^2 + \lambda_3(\phi_1^\dagger\phi_1)(\phi_2^\dagger\phi_2) + \lambda_4(\phi_1^\dagger\phi_2)(\phi_2^\dagger\phi_1) \\
& + \frac{1}{2}\left[\lambda_5(\phi_1^\dagger\phi_2)^2 + \text{h.c.}\right] + \boxed{\left[(\lambda_6(\phi_1^\dagger\phi_1) + \lambda_7(\phi_2^\dagger\phi_2))(\phi_1^\dagger\phi_2) + \text{h.c.}\right]}_{hard} \\
& - \frac{1}{2}\left\{m_{11}^2(\phi_1^\dagger\phi_1) + \boxed{\left[m_{12}^2(\phi_1^\dagger\phi_2) + \text{h.c.}\right]}_{soft} + m_{22}^2(\phi_2^\dagger\phi_2)\right\}
\end{aligned}
$$

The (ϕ_1, ϕ_2) mixing <–> Z_2 symmetry: $\phi_1 \to -\phi_1$, $\phi_2 \to \phi_2$ (or 1<->2)

Z_2-symmetry if $\Rightarrow \lambda_6 = \lambda_7 = m_{12}^2 = 0$
(it protects tree-level FCNC Weinberg, Glashow'77)

In general 14 parameters: $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6, \lambda_7, m_{11}^2, m_{22}^2$, m_{12}^2

Fixing v: 14-1=13 parameters (SM: 2-1=1 parameter)

Lee, Diaz-Cruz, Mendez, Haber, Pomarol, Barroso, Santos, Hollik, Djouadi, Illana, Branco,Gunion, Akeroyd, Arhrib, Dubnin, Froggatt, Sher, Pilaftsis, Carena...

“Natural” 2HDM: soft violation of Z_2 symmetry and weak CP violation

•Naturalness criterium a’la d’Hooft (1979) - naturally small parameters
if L acquires extra symmetry when they vanishes

•Z_2-symmetry introduced by Weinberg and Glashow:
“Natural conservation laws for neutral current, Natural Falvour Conservation (Branco..)

However: Z_2 symmetry = no CP violation in Higgs sector!
•Good motivation for a soft violation of Z_2-symmetry
all breaking of this symmetry in radiative corrections may be absorbed in a renormalization of m_{12}^2 itself.

•Potential: soft violation Z_2-symmetry by m_{12}^2

•Yukawa interaction:with Z_2-symmetry (Model I and Model II)

Naturally small CPV and FCNC: $\lambda_6 = \lambda_7 = 0$, $|m_{12}^2|$ small (Re $\sim$ Im)

The minimum condition

For $\boxed{\overline{m}_{12}^2 = 2v_1v_2(\nu + i\delta)}$

ν is arbitrary

while imaginary part δ:

$$\delta = \underbrace{0}_{Z_2\ sym} + \underbrace{\frac{\overline{\lambda}_5}{2}}_{soft} + \underbrace{\frac{\overline{\lambda}_{67}}{2}}_{hard}$$

Naturalness and non-decoupling

Soft Z_2 violation and special rephasing with real vaccum expectations values:

•CPV governed by a single parameter $\sim Imm_{12}^2$

•naturally small CPV and FCNC effects:

$\nu = \mathrm{Re}\, m_{12}^2/2v_1v_2$ and $\delta = \mathrm{Im}\, m_{12}^2/2v_1v_2$ both small.

Decoupling property and masses of heavy Higgs bosons depends on ν

•$M_{H^\pm}^2 = v^2[\nu - \frac{1}{2}\mathrm{Re}(\lambda_4 + \lambda_5 + \lambda_{67})]$, $M_{A^0}^2 = v^2[\nu - \lambda_5]$

•small $\nu \to$ non-decoupling observed

eg. h SM-like (tree) with deviation from SM for loop couplings due to heavy Higgs

•unitarity constraints (for λ_i) crucial if heavy Higgs bosons exist and ν is small

•large $\nu \to$ decoupling, h SM-like (tree and loop couplings)

CP violation: $\text{Im}\,\lambda_5 \neq 0$ (here only soft Z_2 viol.)

if $\nu \propto \text{Re}(m_{12}) \propto \text{Re}\,\lambda_5$ small
is large $\delta \propto \text{Im}\,\lambda_5$ natural?
Weak CP-violation $\rightarrow$ small $\delta \sim Im\lambda_5$

All three neutral Higgs states mix

$$M = v^2 \begin{pmatrix} \lambda_1 c_\beta^2 + \nu s_\beta^2 & (\lambda_{345} - \nu) c_\beta s_\beta & -\frac{1}{2}\text{Im}\lambda_5\, s_\beta \\ (\lambda_{345} - \nu) c_\beta s_\beta & \lambda_2 s_\beta^2 + \nu c_\beta^2 & -\frac{1}{2}\text{Im}\lambda_5\, c_\beta \\ -\frac{1}{2}\text{Im}\lambda_5\, s_\beta & -\frac{1}{2}\text{Im}\lambda_5\, c_\beta & -\text{Re}\,\lambda_5 + \nu \end{pmatrix}$$

When $\text{Im}\,\lambda_5 = 0$, a standard block-diagonal structure (CP consv.)
h_1, h_2, h_3 states if off-diagonal terms appear (mixing, CP violation)
If no mixing : h, H, A states with definite CP-parity (CP even and CP odd)
and with masses M_h, M_H, M_A.

(Discussing masses we use $\mu^2 = \nu v^2$)

CP conserving case: λ_i in terms of masses, $\mu^2 = \nu v^2$ etc.

$$\lambda_1 v^2 = \frac{1}{\cos^2\beta}\{M_H^2 \cos^2\alpha + M_h^2 \sin^2\alpha\} - \mu^2 \tan^2\beta$$
$$\lambda_2 v^2 = \frac{1}{\sin^2\beta}\{M_H^2 \sin^2\alpha + M_h^2 \cos^2\alpha\} - \mu^2 \cot^2\beta$$

Remaining λ_i:

$$\lambda_5 v^2 = -M_{A^0}^2 + \mu^2$$
$$\lambda_4 v^2 = M_{A^0}^2 - 2M_{H^\pm}^2 + \mu^2$$
$$\lambda_3 v^2 = 2M_{H^\pm}^2 + \frac{\sin 2\alpha}{\sin 2\beta}(M_H^2 - M_h^2) - \mu^2$$

Physical content of potential

- trilinear couplings
- quartic couplings

In addition:

- couplings to gauge bosons: hWW, etc
- couplings to fermions (Yukawa) in Model II

Note, if selfcouplings are expressed in terms of masses, also μ enters!

$$\begin{aligned} g_{hhh} &= -3v\Big[-\cos\beta\sin^3\alpha\,\lambda_1 + \sin\beta\cos^3\alpha\,\lambda_2 - \tfrac{1}{2}\sin 2\alpha\cos(\beta+\alpha)\lambda_{345}\Big], \\ &= \frac{-3g}{\sin 2\beta\, M_W}\Big[(\cos\beta\cos^3\alpha - \sin\beta\sin^3\alpha)M_h^2 - \cos^2(\beta-\alpha)\cos(\beta+\alpha)\mu^2\Big], \end{aligned}$$

Boudjema,Semenov,Dubinin,Hollik,...

Basic couplings to gauge bosons $V = W/Z$ and fermions u, d-types

Using relative "basic couplings":

$$\chi_j = \frac{g_j}{g_j^{\mathrm{SM}}}, \qquad \text{for } h, H, A \text{ or } (h_1, h_2, h_3)$$

with $j = V, u, d$, we get for h

$$\begin{aligned} \chi_V^h &= \sin(\beta - \alpha) \\ \chi_u^h &= \sin(\beta - \alpha) + \cot\beta \cos(\beta - \alpha) \\ \chi_d^h &= \sin(\beta - \alpha) - \tan\beta \cos(\beta - \alpha) \end{aligned}$$

α –parameterizes mixing among the two neutral CP-even Higgs fields [eq. $(-\pi,\ 0)$]

Selfcouplings in terms of observables: masses and relative coupl.

Using relative couplings one obtains

$$g_{hhh} = \frac{-3g}{2M_W}\Big[(\cos^2\alpha\,\chi_u^h + \sin^2\alpha\,\chi_d^h)(M_h^2 - \mu^2) + \chi_V^h\mu^2\Big]$$

A relative coupling for hH^+H^-, (similarly for H):

$$\chi^h_{H^\pm} \equiv -\frac{v g_{hH^+H^-}}{2iM^2_{H^\pm}} = \left(1 - \frac{M_h^2}{2M^2_{H^\pm}}\right)\chi_V^h + \frac{M_h^2 - \mu^2}{2M^2_{H^\pm}}(\chi_u^h + \chi_d^h)$$

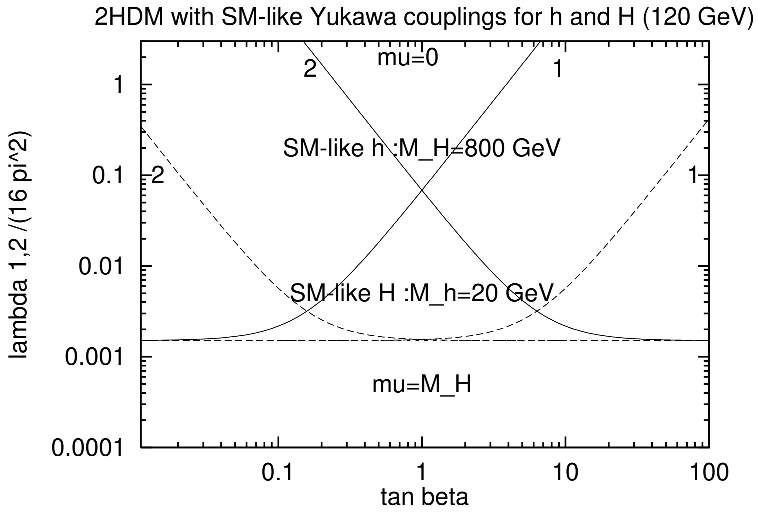
Very useful parametrizations for SM-like scenarios

$\chi^h_{H^\pm}$ “finite” for “large” $M^2_{H^\pm}$ (non-decoupling for small μ^2)
important for $\gamma\gamma h$ loop-coupling.

Perturbativity: λ_i in terms of masses and basic couplings

$$\lambda_1 v^2 = (1+\tan\beta^2)M_H^2 - \chi_d^2[M_H^2 - M_h^2] - \mu^2\tan^2\beta$$
$$\lambda_2 v^2 = (1+\cot\beta^2)M_H^2 - \chi_u^2[M_H^2 - M_h^2] - \mu^2\cot^2\beta$$

Take $\chi_d = \chi_u = 1$ for SM-like Higgs boson with mass 120 GeV $\lambda_{1,2} < (4\pi)^2$



SM-like Higgs h or H:

- h (M_H=800GeV)
- H (M_h=20GeV)

No problem...however for small μ^2 region of $\tan\beta$ maybe limited

Pattern relations: CP consv. and violation

We found that for each neutral Higgs boson at tree level:

$$(\chi_u - \chi_V)(\chi_V - \chi_d) + \chi_V^2 = 1$$

or

$$(\chi_u + \chi_d)\chi_V = 1 + \chi_u \chi_d.$$

Also,

$$\tan^2\beta = \frac{(\chi_V - \chi_d)^*}{(\chi_u - \chi_V)} = \frac{1 - |\chi_d|^2}{|\chi_u|^2 - 1}$$

Radiative corrections at the level of *few percents*.

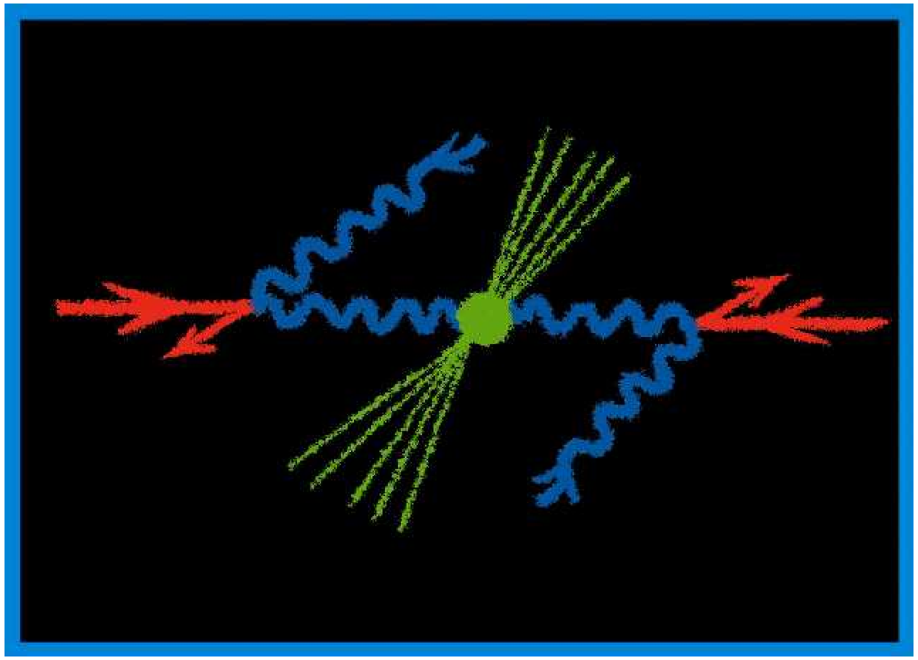
Photon Colliders

based on laser Compton backscattering

- Characteristic photon energy $E_\gamma \approx 0.8 E_{e^+e^-}$.
- Luminosity $\mathcal{L} \approx 0.2 \mathcal{L}_{ee}$, annual luminosity $\mathcal{L} \approx 100\ \mathrm{fb}^{-1}$
- Mean energy spread $< \Delta E_\gamma > \equiv$

$$\equiv \sqrt{< E_\gamma^2 > - < E_\gamma >^2} \approx (0.05 \div 0.07) E_\gamma.$$

- Mean photon helicity $< \lambda_\gamma > \approx 0.9 \div 0.95$



If LHC and e^+e^- Linear Colliders

Standard-Model-like scenario:

- One Higgs boson will be discovered with mass $M_h > 115$ GeV. Either the SM Higgs boson OR one Higgs boson from two: h and H ($M_h < M_H$) of the 2HDM
- The measured decay widths (or coupling constants squared) to quarks, charged leptons, EW gauge bosons and gluons in agreement with their SM values Γ_i^{SM} within the experimental precision

$$\left| \frac{\Gamma_j^{\mathrm{exp}}}{\Gamma_j^{\mathrm{SM}}} - 1 \right| = \left| \left(\frac{g_j}{g_j^{\mathrm{SM}}} \right)^2 - 1 \right| \lesssim \delta_j \ll 1, \text{ where } j = u, d, V.$$

- No other Higgs boson will be discovered.

Either they are weakly coupled with the Z boson, gluons and quarks, or they are sufficiently heavy (above O (800 GeV) to escape observation.

- All other new particles are heavier than the discovery limits of LHC and the e^+e^- Linear Collider.

SM-like scenarios

χ_j differ by ϵ from ± 1, with $|\epsilon_i| \leq \delta_i$. Additional constraints on these ϵ_i follow from the pattern relation.

The loop-induced transition rate $h \to \gamma\gamma$ and $h \to Z\gamma$ will differ from the SM prediction due to the charged Higgs boson contribution, proportional to the trilinear Higgs coupling hH^+H^-:

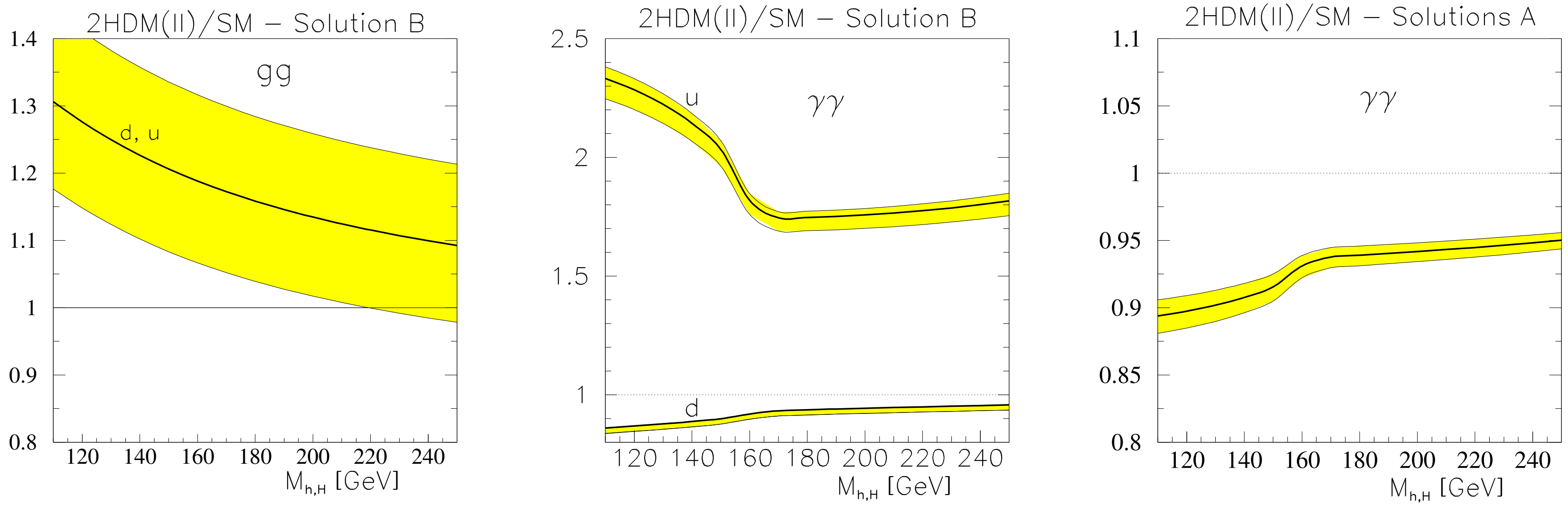
$$\chi^h_{H^\pm} \equiv -\frac{v g_{hH^+H^-}}{2M^2_{H^\pm}} = \left(1 - \frac{M_h^2}{2M^2_{H^\pm}}\right)\chi_V^h + \frac{M_h^2 - \mu^2}{2M^2_{H^\pm}}(\chi_u^h + \chi_d^h)$$

Two different types of realizations of a SM-like limit of the 2HDM II:

- solutions A all basic (relative) couplings are close to 1 or all are close to -1
- solutions B, one basic coupling, χ_u or χ_d, has opposite sign to the other two

solution	basic couplings	$\lvert\chi_{gg}\rvert^2$	$\lvert\chi_{\gamma\gamma}\rvert^2$	$\lvert\chi_{Z\gamma}\rvert^2$
$A_{h\pm}$	$\chi_V \approx \chi_d \approx \chi_u \approx \pm 1$	1.00	0.90	0.96
$B_{h\pm d}$	$\chi_V \approx -\chi_d \approx \chi_u \approx \pm 1$	1.28	0.87	0.96
$B_{h\pm u}$	$\chi_V \approx \chi_d \approx -\chi_u \approx \pm 1$	1.28	2.28	1.21

The two-gluon decay-width and two-photon decay-width



The shaded bands reflecting experimental uncertainties

Note, that

$$|\chi_{\gamma\gamma}|^2 = 1 + \left(\frac{M_h^2}{2M_{H+}^2}\right) - \left(\frac{\mu^2}{M_{H+}^2}\right).$$

Determination of CP violating H-A mixing from $h_2 \to WW,\ ZZ$ decays in 2HDM: PLC and comparison with LHC and LC.

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ECFA Study
SUSY/Higgs working group meeting
CERN, March 18-19, 2004
LCWS 2004, Paris

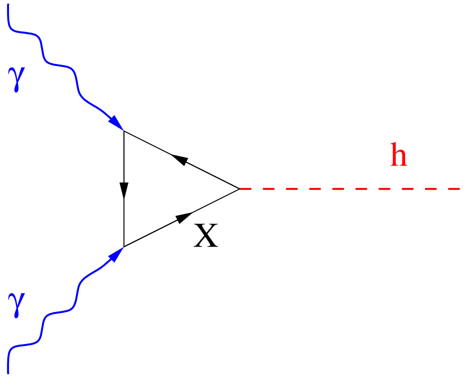
Outline

- Higgs boson production and decays to WW and ZZ at PLC JHEP 0211 (2002) 034 [hep-ph/0207294]
- Weak CP violation in SM-like 2HDM (II) at PLC hep-ph/0307175; hep-ph/0403138
- Comparison with LHC and LC in LHC/LC WG, hep-ph/0404024

$\gamma\gamma \to \mathcal{H} \to WW,\ ZZ$

Higgs boson production at the Photon Collider

Production cross section is proportional to the two-photon width



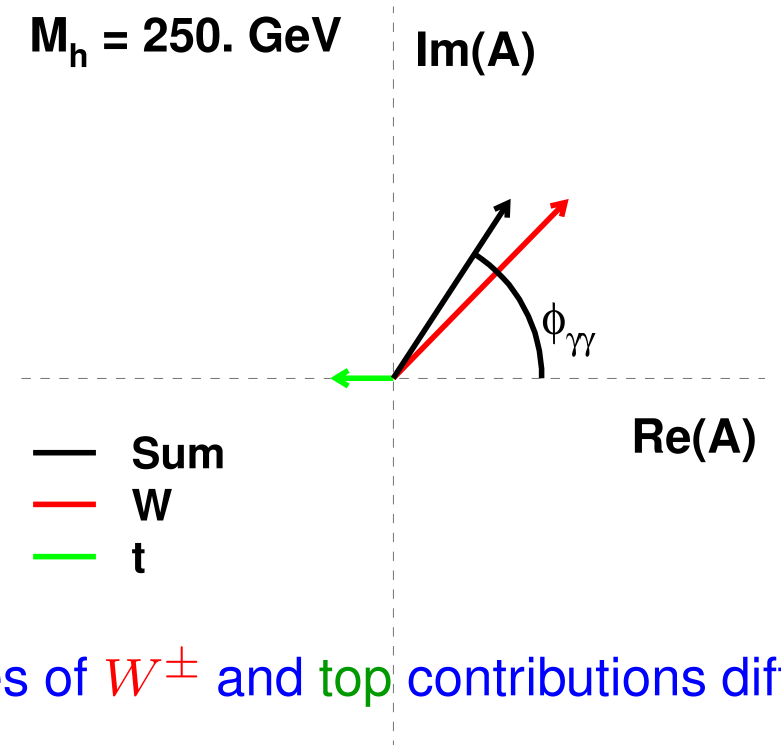
$$\Gamma(h \to \gamma\gamma) = \frac{G_F \alpha^2 M_h^3}{128\sqrt{2}\,\pi^3} \cdot |\mathcal{A}|^2$$

where:

$$\mathcal{A} = A_W(M_W) + \sum_f N_c Q_f^2 A_f(M_f) + \ldots$$

two-photon amplitude

In SM, dominant contributions to two-photon amplitude $\mathcal{A}$ are due to $W^\pm$ and top loops.



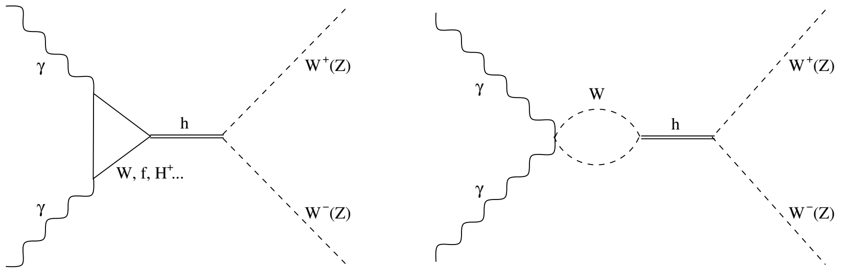
Phases of $W^\pm$ and top contributions differ !

The phase of the amplitude $\phi_{\gamma\gamma}$ depends on Higgs-boson couplings !

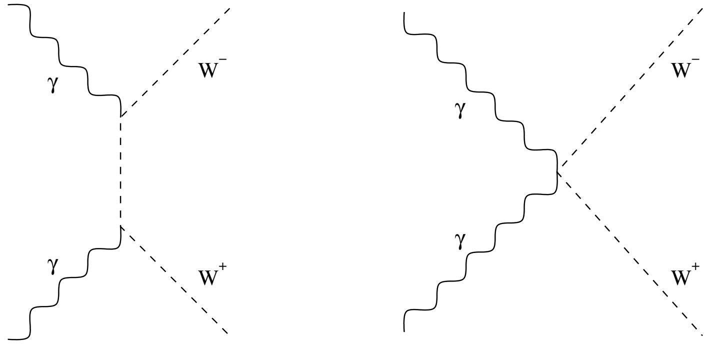
$\gamma\gamma \to \mathcal{H} \to WW,\ ZZ$

We consider Higgs boson production and decays to WW/ZZ, for masses 200–350 GeV.

For resonant $\gamma\gamma \to h \to W^+W^-$ signal

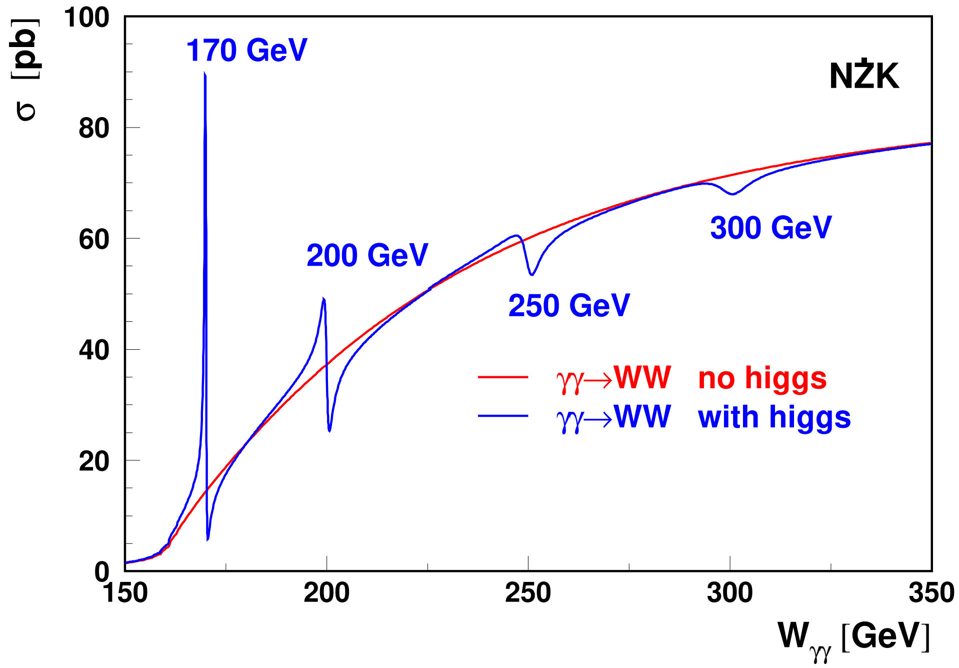


there is a large non-resonant bg.



Large interference effects are expected in the considered mass range (Morris,Ginzburg,..)

J=0



Interference is sensitive to the phase of the two-gamma amplitude

$\gamma\gamma \rightarrow \mathcal{H} \rightarrow WW,\ ZZ$

Simulation

$\gamma\gamma$ spectra from **CompAZ** hep-ex/0207021

$\gamma\gamma \rightarrow W^+W^-,\ ZZ$ events
generated with PYTHIA 6.152

events reweighted to take into account:

- beam polarization
- Higgs production and interference

detector simulation with SIMDET v. 3.01

total $\gamma\gamma$ luminosity: 600 – 1000 fb^{-1}

High $W_{\gamma\gamma}$ peak: 75 – 115 fb^{-1}

for $\sqrt{s_{ee}}$ = 305 – 500 GeV

Parametrization

"Measured" invariant mass distribution for selected W^+W^- and ZZ events is described by convolution of:

- Analytical luminosity Spectra **CompAZ**
- Cross section formula
  for signal + background + interf.
- Invariant mass resolution
  parametrized as a function of $W_{\gamma\gamma}$

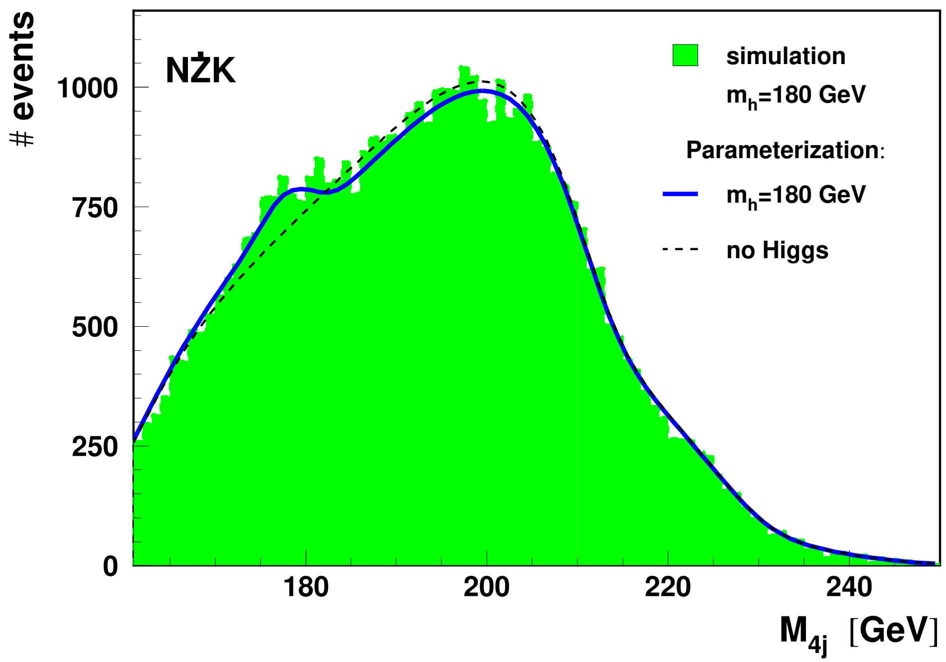
$\Rightarrow$ mass spectra can be calculated for any $\sqrt{s_{ee}}$ and m_h without time-consuming MC simulation

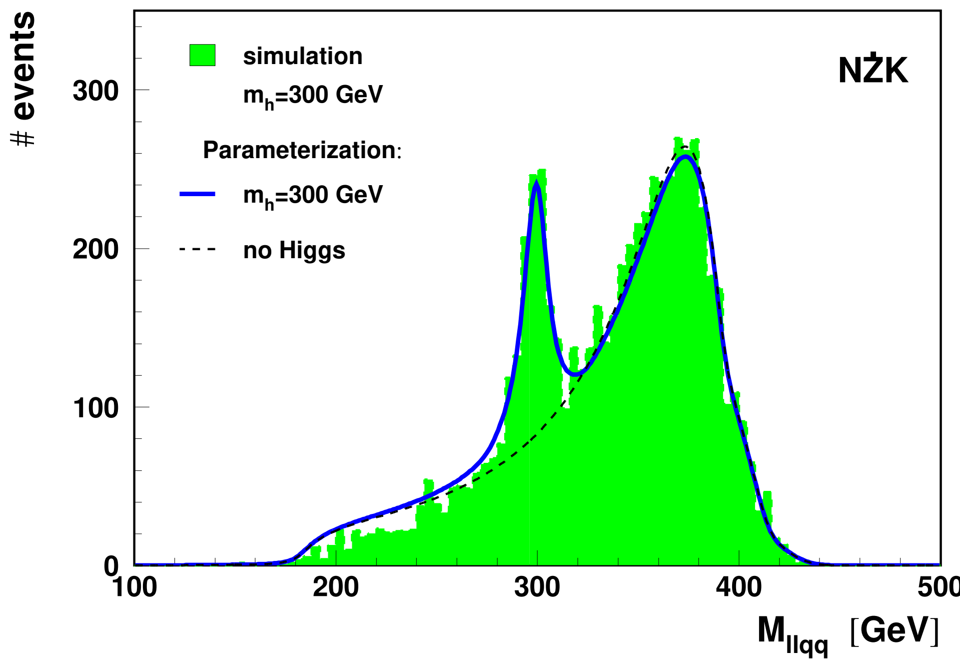
$\Rightarrow$ can be used for fast simulation and fitting

$\gamma\gamma \to \mathcal{H} \to WW,\ ZZ$

Comparison of parametrization with full simulation:

W^+W^- ZZ





From the simultaneous fit to the observed W^+W^- and ZZ mass spectra both the two-photon width $\Gamma_{\gamma\gamma}$ and phase $\phi_{\gamma\gamma}$ can be determined.

For SM: $\Gamma_{\gamma\gamma}$ with precision $\sim 4-9\%$ $\phi_{\gamma\gamma}$ with precision $40-120$ mrad

A simple 2HDM(II) with CP violation

“SM-like” 2HDM(II)

We consider SM-like **solution B_h**

Basic couplings, relative to SM:

$$\chi_x = g_{\mathcal{H}xx}/g^{SM}_{\mathcal{H}xx} \qquad \mathcal{H} = h, H, A$$

	h	H	A
χ_u	-1	$-\frac{1}{\tan\beta}$	$-i\,\gamma_5\,\frac{1}{\tan\beta}$
χ_d	$+1$	$-\tan\beta$	$-i\,\gamma_5\,\tan\beta$
χ_V	$\cos(2\beta)$	$-\sin(2\beta)$	0

CP conserving version :

couplings depend on $\tan\beta$ only.

we set

$$M_{H^\pm} = 800\ GeV \quad \nu = 0$$

Note:here $\mathrm{B}_h - -|\chi^h_u| = |\chi^h_d|$

CP violation

Mass eigenstates of the neutral Higgs-bosons h_1, h_2 and h_3 do not need to match CP eigenstates h, H and A.

We consider weak CP violation through a small mixing between H and A states:

$$\chi^{h_1}_X \approx \chi^h_X$$
$$\chi^{h_2}_X \approx \chi^H_X \cdot \cos\Phi_{HA} + \chi^A_X \cdot \sin\Phi_{HA}$$
$$\chi^{h_3}_X \approx \chi^H_X \cdot \sin\Phi_{HA} - \chi^A_X \cdot \cos\Phi_{HA}$$

$\Rightarrow$ additional parameter: $\Phi_{HA}(-s_3)$

CP-violating mixing phase

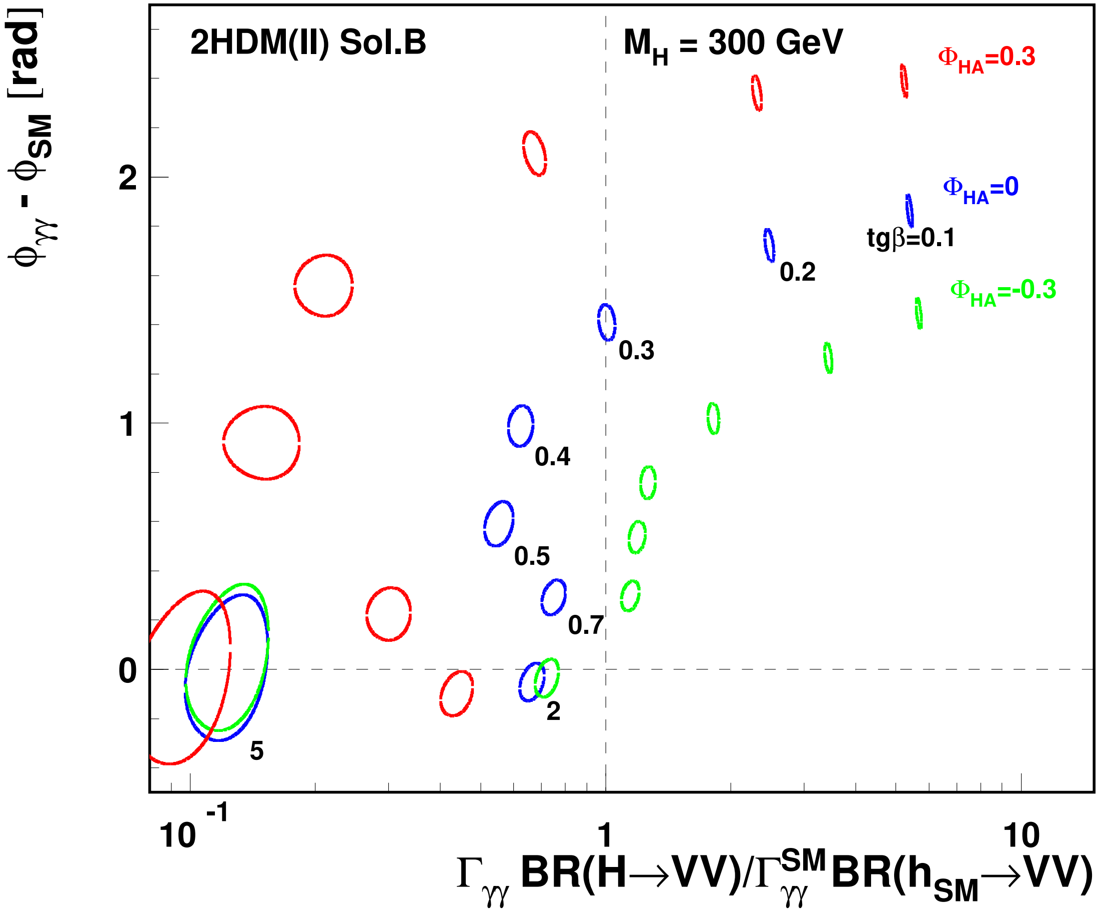
We consider h_2 production and decays

Measurement at PLC: systematic uncertainties

Higgs boson h_2

Two-photon width and phase measurement for different $\tan\beta$ and Φ_{HA}

M_{h_2} = 300 GeV



1σ contours for 1 year of PC running

statistical errors only

M_h=120 GeV, M_{H+}=800 GeV

Expected precision at PLC:
(for small mixing i.e. $\Phi_{HA} \sim 0$)

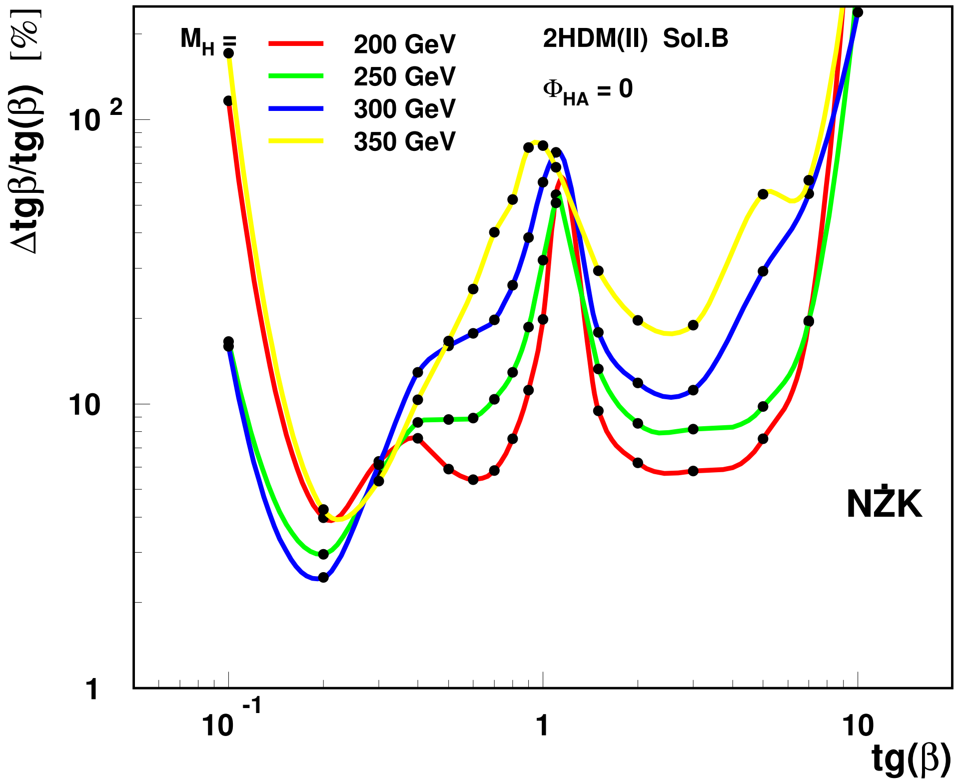
- $\sim$ 10 % for $\tan\beta$
- $\sim$ 100 mrad for Φ_{HA} (for low $\tan\beta$)

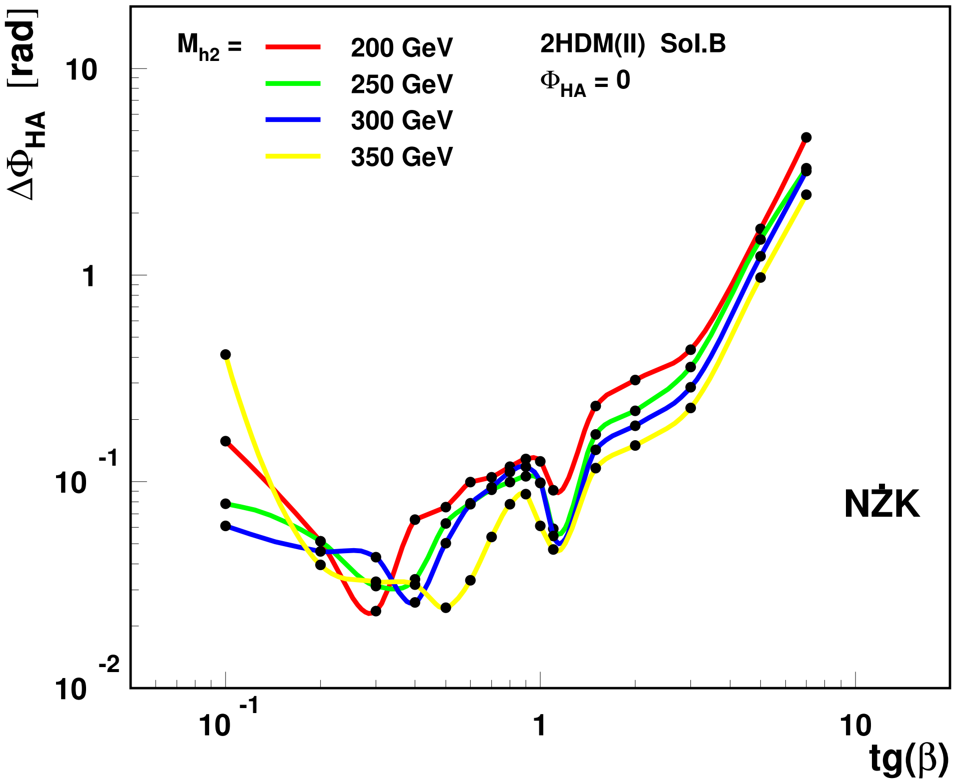
Determination of $\tan\beta$ and ϕ_{HA} at PLC

Higgs boson h_2

Solution B_h (with CP violation) $\Rightarrow$ two free parameters ($\tan\beta$ and Φ_{HA})

Expected precision in $\tan\beta$ and Φ_{HA} determination at PLC (stat.+sys. errors)





CP-violating HA mixing angle can be precisely measured, if $\tan\beta$ is not too large

Can we distinguish this case from CP conserving 2HDM (II) ? (with $\tan\beta$ and α)

Comparison LHC-LC-PLC

LHC

LHC

In the mass range 200-350 GeV Higgs production at LHC is dominated by the gluon fusion process (top loop)

$$\sigma(gg \to h) \sim \chi_t^2$$

WW fusion process ($\sim$ 15%)

$$\sigma(qq \to qqh) \sim \chi_V^2$$

Measurement of

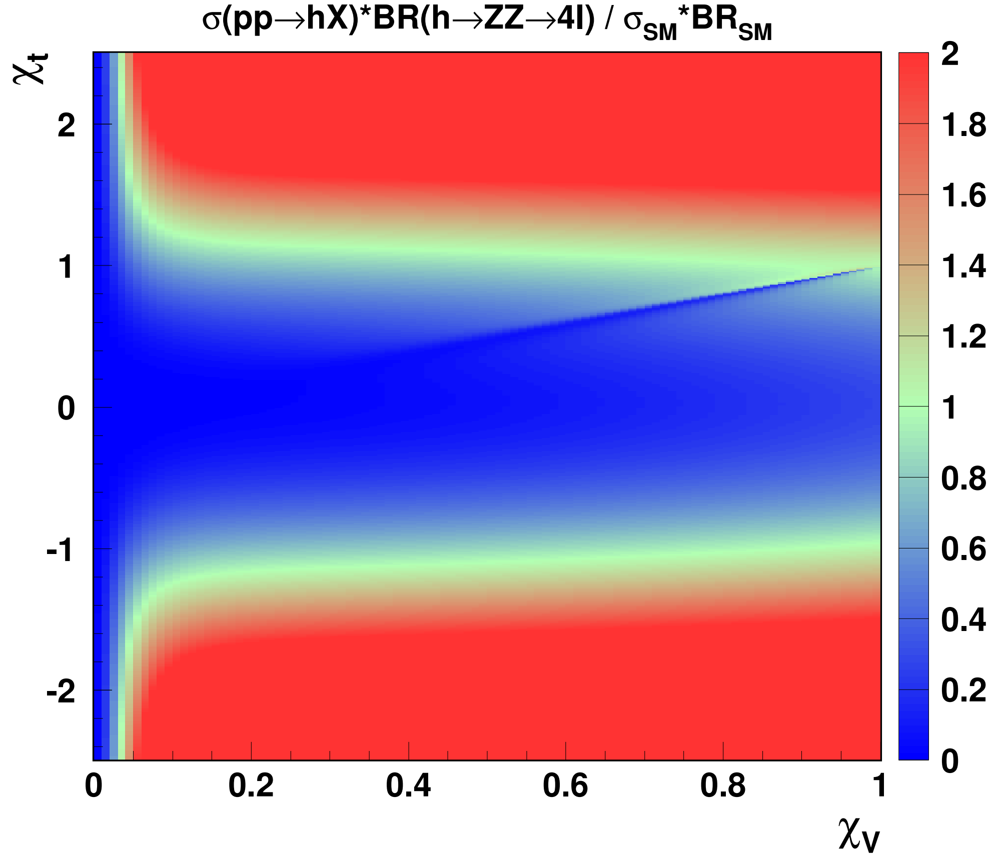
$$\sigma(pp \to hX) \cdot BR(h \to ZZ \to 4l)$$

is possible with precision $\sim 15\%$

(SM-like scenario, 30 fb^{-1})

CMS TN/95-018, CMS CR/2002-020

Cross section relative to SM (250 GeV)

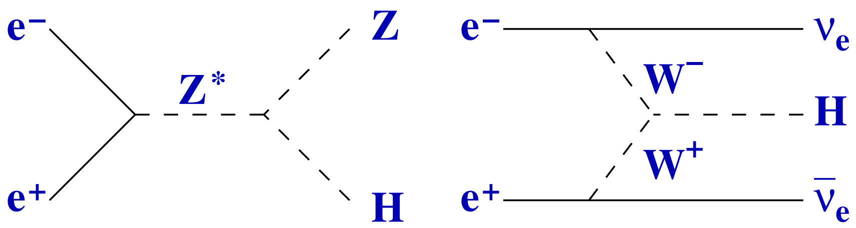


This will constrain the $|\chi_t|$ value, provided χ_V is not too small.

LC

LC

At LC, two processes contribute to the Higgs boson production



Cross section is sensitive only to χ_V

Measurement of

$$\sigma(e^+e^- \to hX) \cdot BR(h \to WW/ZZ)$$

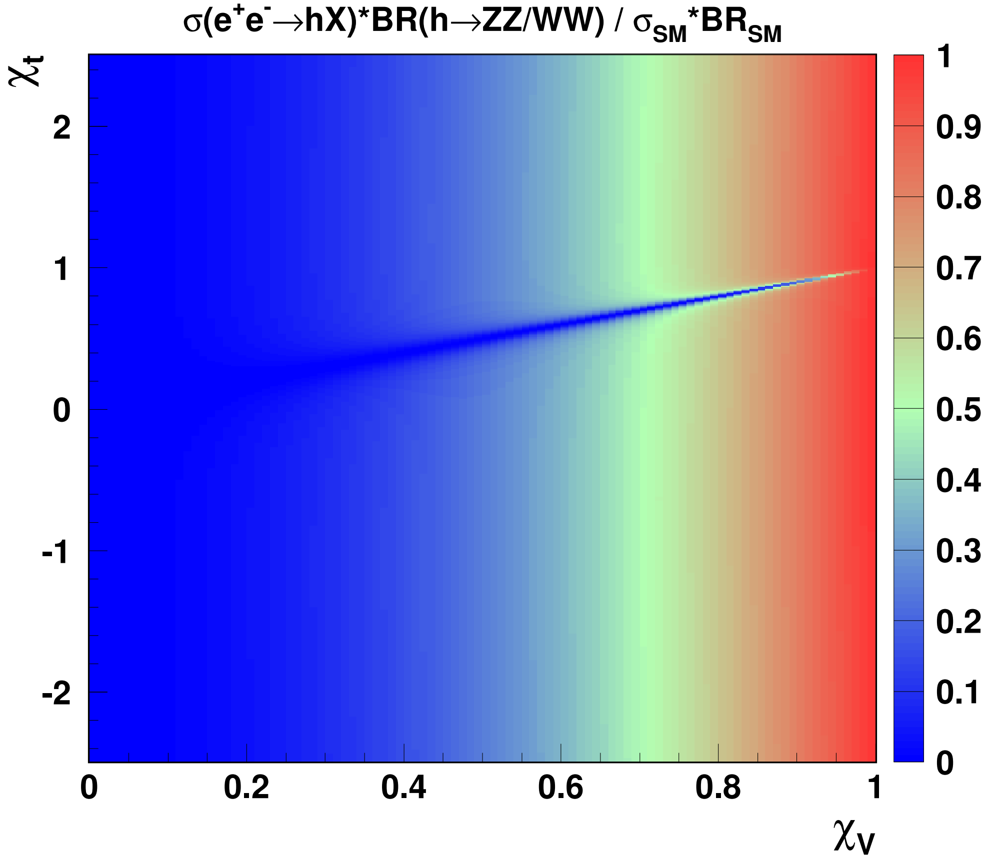
is possible with precision $\sim 4-7\%$

N.Meyer LC-PHSM-2003-066

(SM-like scenario, $\sqrt{s} = 500\ GeV$, 500 fb^{-1})

This will constrain the χ_V value

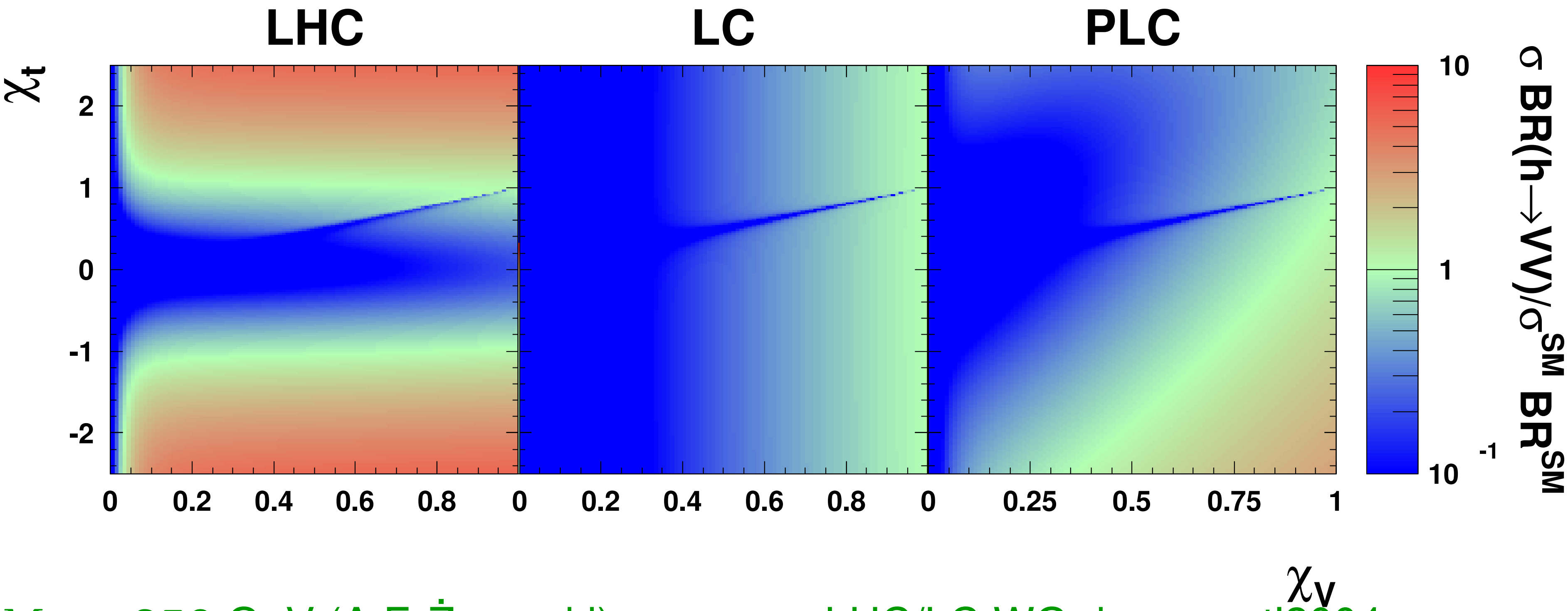
Cross section relative to SM



CP conserving 2HDM (II)

Can we profit from independent measurements at LHC,LC and PLC?

Expected Higgs-boson h production rates times W^+W^-/ZZ branching ratios, relative to SM predictions, as a function of basic relative couplings:

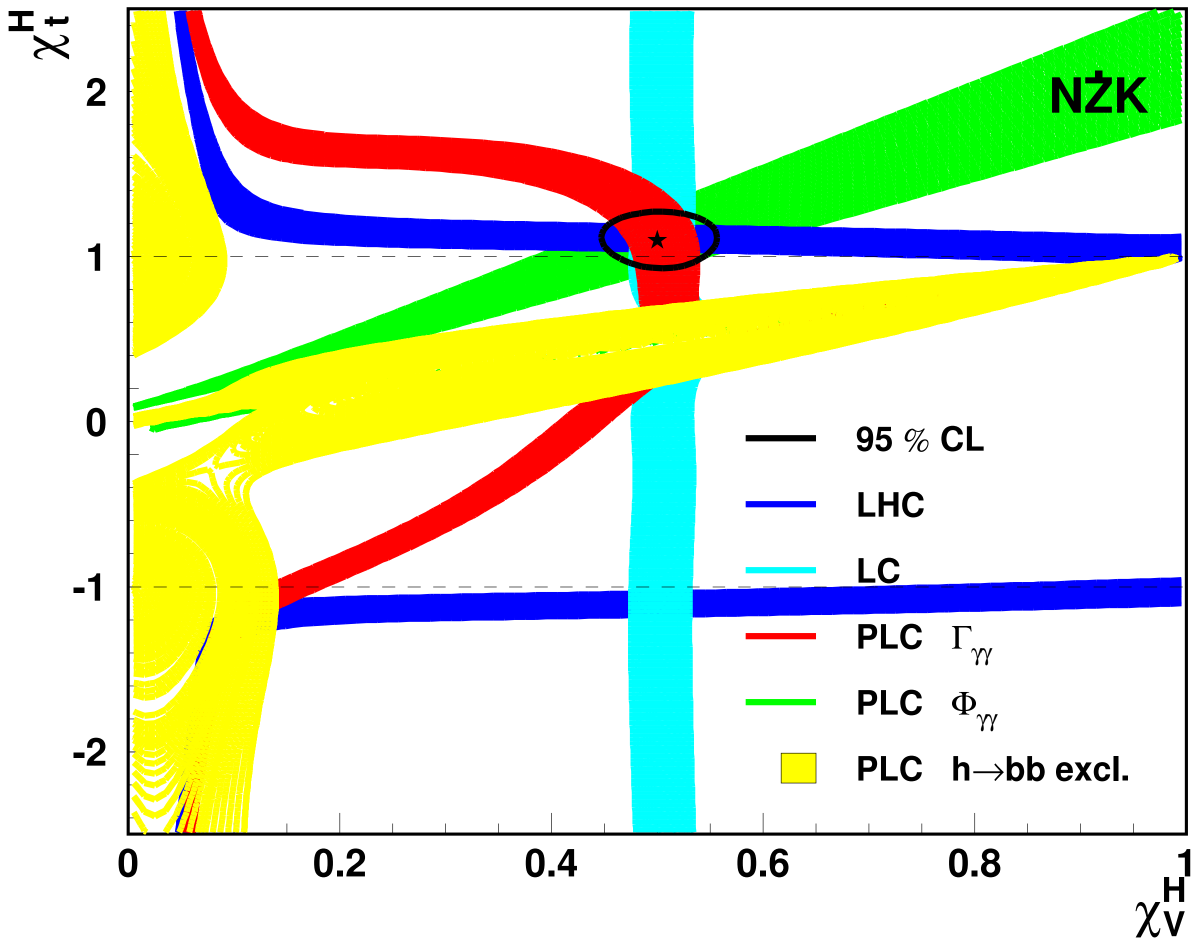


$M_h = 250$ GeV (A.F. Żarnecki) LHC/LC WG document'2004

Comparison LHC and LC and PLC

Allowed coupling values (1 σ) from cross section measurements at LHC, LC and PLC, and the phase measurement at PLC.

$\chi_V = 0.5 \quad \chi_t = 1.1 \quad M_H = 300$ GeV



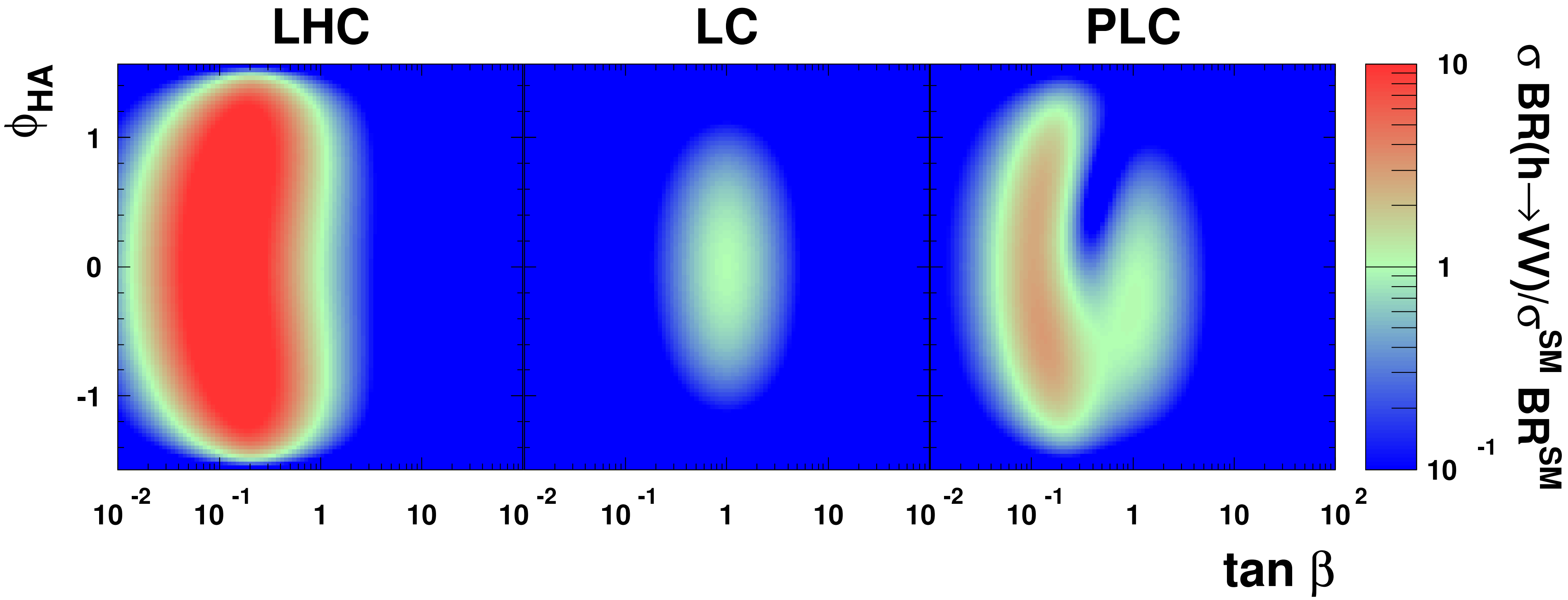
Consistency of all these measurements verifies the coupling structure of the model

statistical errors only

Comparison

2HDM (II) sol. B_h (with weak CP violation)

Expected Higgs-boson production rates times W^+W^-/ZZ branching ratios, relative to SM predictions, as a function of $\tan\beta$ and CP-violating mixing angle Φ_{HA}

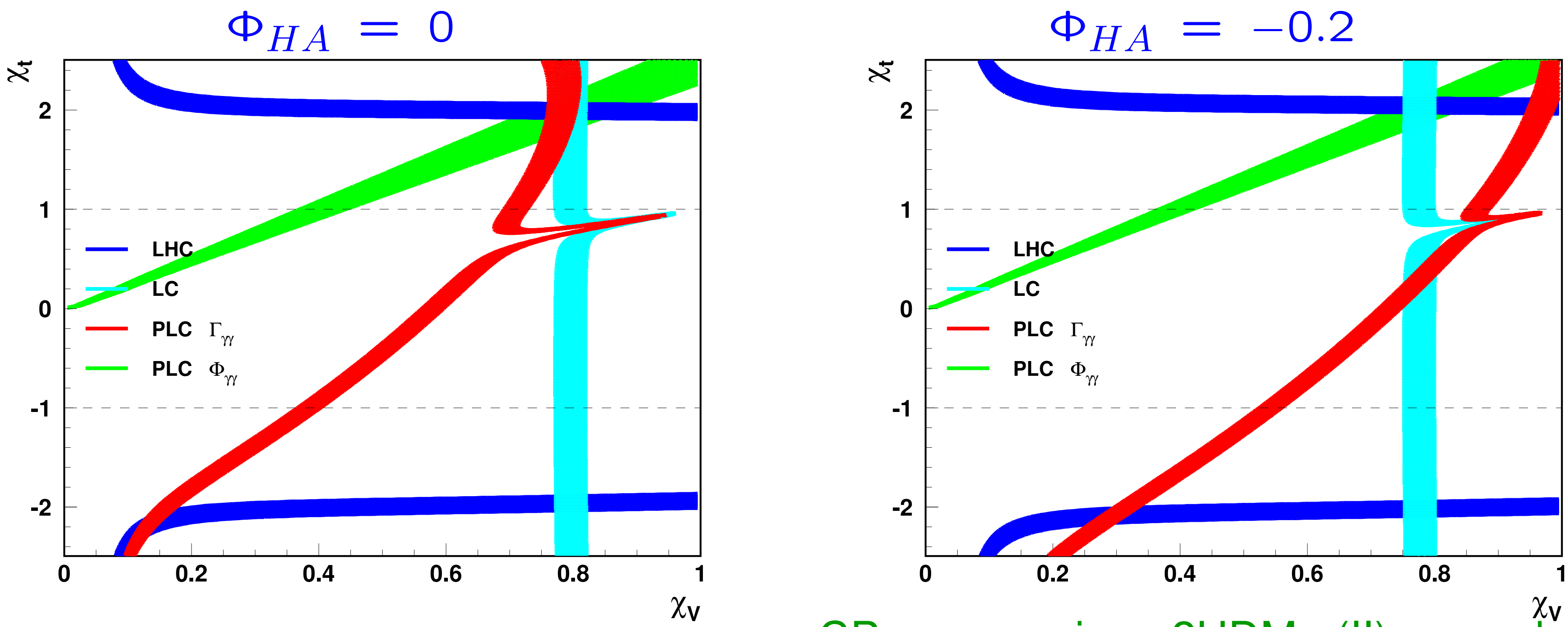


$M_{h_2} = 250$ GeV

Comparison based on χ_t and χ_V

LHC $\oplus$ LC $\oplus$ PLC

Only from combined analysis of LHC, LC and PLC measurements we can establish CP violation in 2HDM (II)



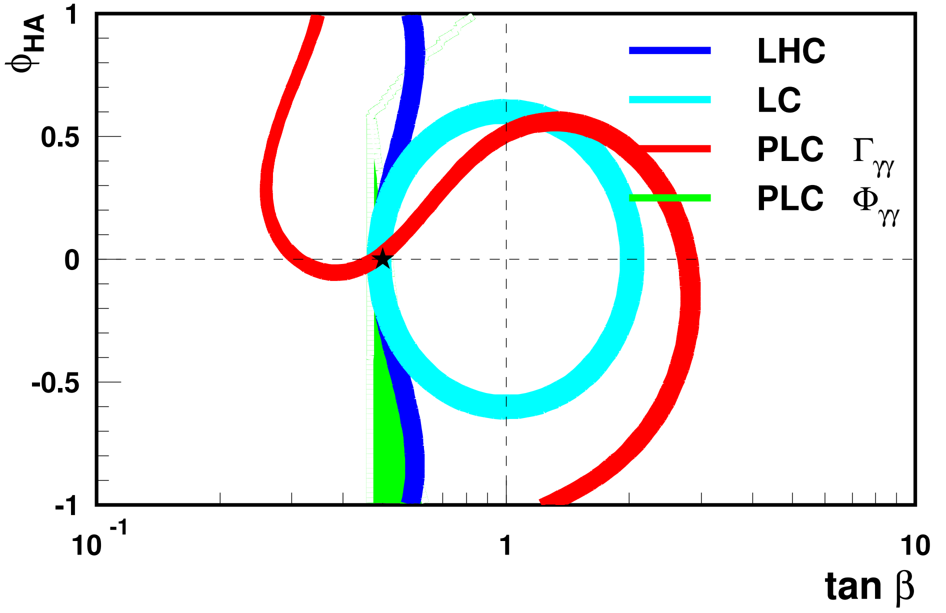
CP conserving 2HDM (II) can be excluded.

Comparison based on $\tan\beta$ and Φ_{HA}

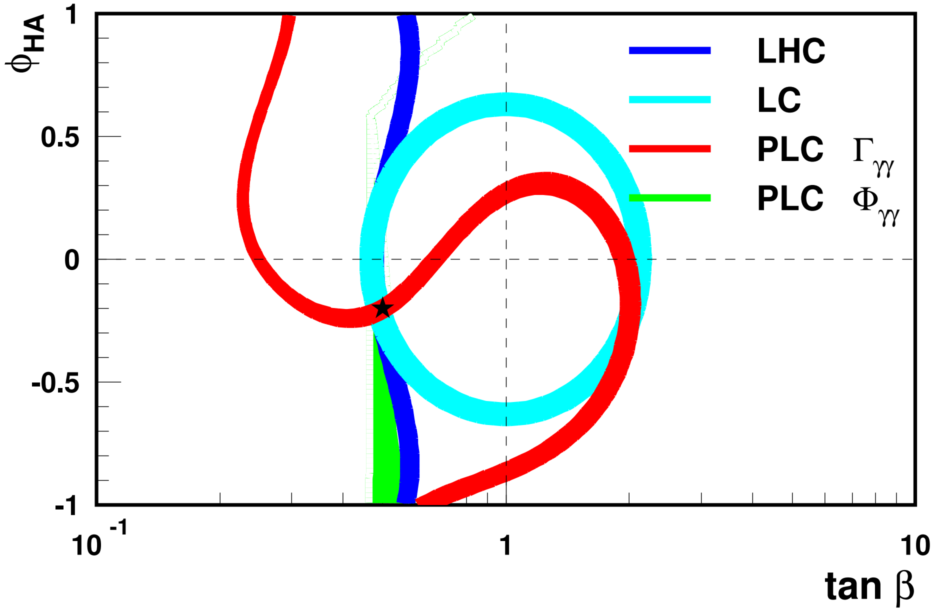
LHC $\oplus$ LC $\oplus$ PLC

Determination of $\tan\beta$ and the CP violating mixing angle Φ_{HA}
for 2HDM (II) solution B_h with CP violation ($M_{h_2} = 250$ GeV, $\tan\beta = 0.5$):

$\Phi_{HA} = 0$



$\Phi_{HA} = -0.2$



Summary

SM-like scenario can be realized at the LHC and e^+e^- Linear Colliders. An anticipated uncertainties in future measurements of the basic couplings of the Higgs boson (in SM case) are known.

Goal: to establish how one can discriminate models, the SM and the 2HDM (II), for a Higgs boson with mass 110–250 GeV (which can be either one of two scalars of the 2HDM, h or H).

Method : as basic quatities we use ratios of measurable couplings of the Higgs boson with quarks and electroweak gauge bosons to their SM values. We obtain a useful pattern relation among them. To establish deviation from SM we study the $\gamma\gamma$ and $Z\gamma$ (also $gluon - gluon$) partial widths.

Types of SM-like scenarios in 2HDM: the pattern relation allows for two types of SM-like solutions:

A - all basic couplings are close to their SM values.
B - some of basic couplings are close to their SM values while others differ in sign from the SM values.

Conclusion: with anticipated high accuracy of measuring $\gamma\gamma$ width at a Photon Collider, this measurement could in general resolve the 2HDM (II) and the SM.

Using W^+W^- and ZZ final states both the partial width $\Gamma_{\gamma\gamma}$ and the phase of the $\mathcal{H} \to \gamma\gamma$ amplitude $\phi_{\gamma\gamma}$ can be measured at the Photon Linear Collider.

Both $\tan\beta$ and the CP violating H–A mixing phase Φ_{HA} can be measured at PLC, assuming solution B_h of 2HDM (II).

In general case, combined analysis of LHC, LC and PLC measurements is needed to establish weak CP violation.