

Measurement of the Higgs-boson couplings and CP properties from decays into WW and ZZ

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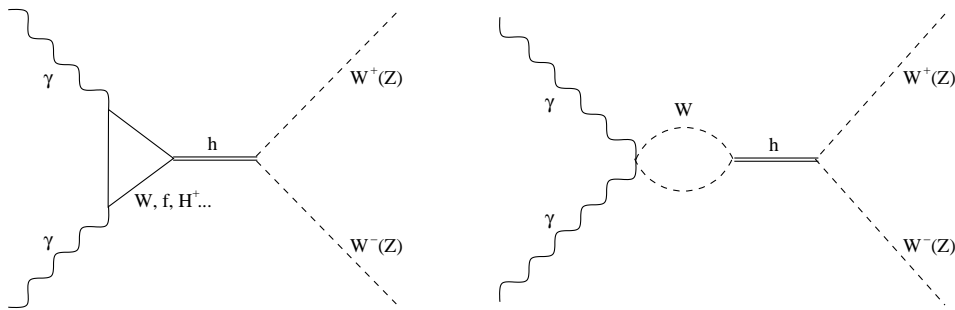
Outline

- $\gamma\gamma \rightarrow (h) \rightarrow W^+W^-, ZZ$
- SM Higgs results hep-ph/0207294
measurement of $\Gamma_{\gamma\gamma}$ and $\phi_{\gamma\gamma}$
- 2HDM(II) results SM-like scenario B
measurement of $\tan\beta$
- 2HDM(II) with CP violation
measurement of H-A mixing phase
- CP violation in generic model
results sent to EPS'2003: hep-ph/0307175

$$\gamma\gamma \rightarrow (h) \rightarrow W^+W^-, ZZ$$

Higgs production and decay

For $M_h > 2M_W$, $h \rightarrow W^+W^-$ dominate:



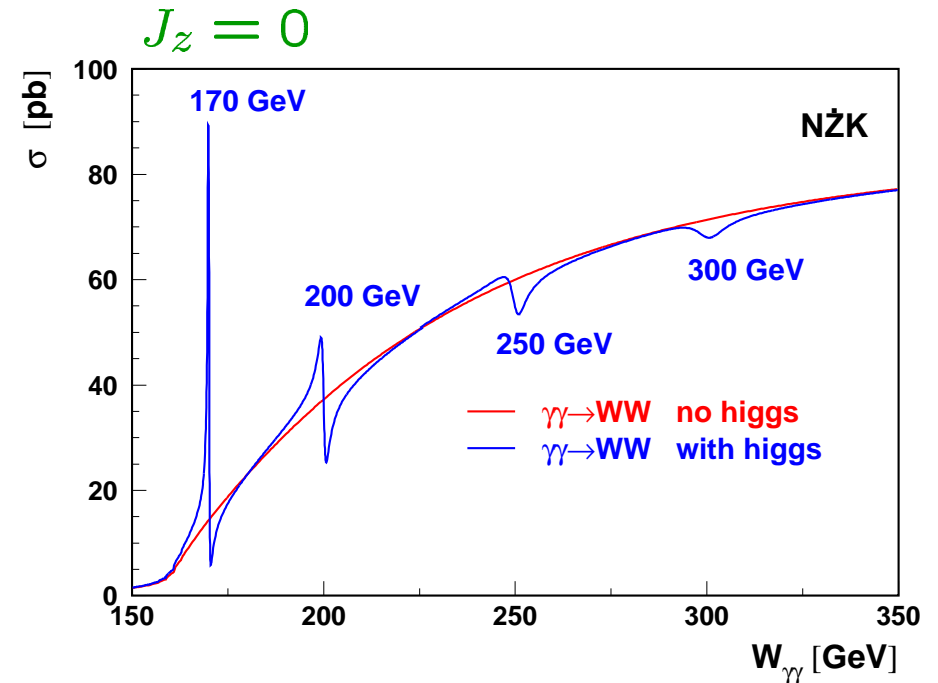
“resonant”

There is a large background from “direct”, non-resonant production $\gamma\gamma \rightarrow W^+W^-$

G.Belanger, F.Boudjema, Phys.Lett.B288(1992)210;
D.A.Morris, et al., Phys. Lett. B323(1994)421;
I.F.Ginzburg, I.P.Ivanov, Phys. Lett. B408(1997)325.

Interference

Resonant and direct amplitudes interfere
Large effects expected:

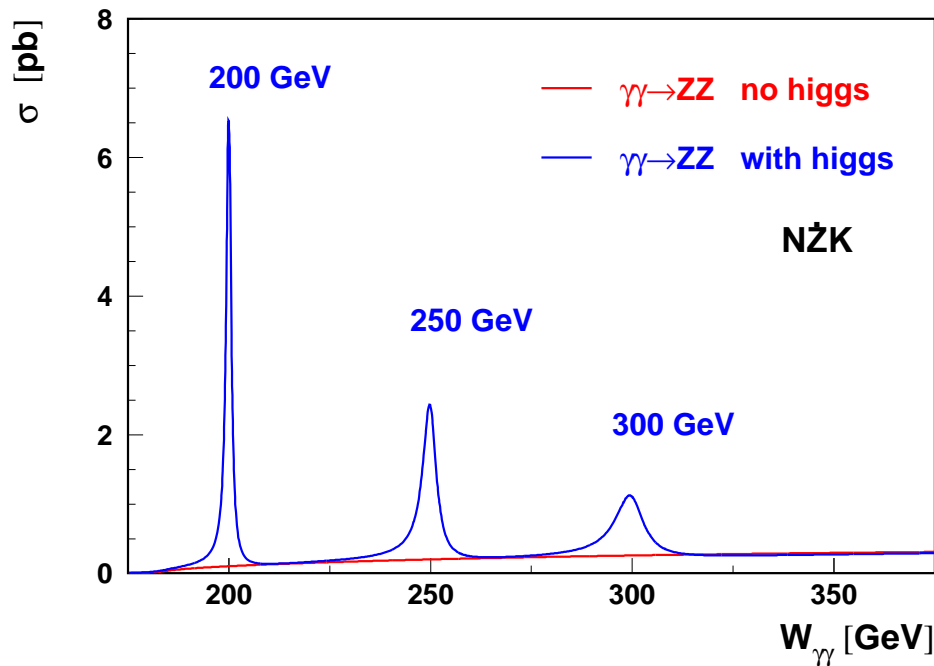


Destructive interference dominates above ~ 200 GeV

$$\gamma\gamma \rightarrow (h) \rightarrow W^+W^-, ZZ$$

$$\gamma\gamma \rightarrow ZZ$$

Non-resonant background only at loop level



⇒ small interference effects

G.J.Gounaris et al., Eur. Phys. J. C13 (2000) 79.

Simulation

$\gamma\gamma$ spectra from **CompAZ** [hep-ex/0207021](https://arxiv.org/abs/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

$$\gamma\gamma \rightarrow (h) \rightarrow W^+W^-, ZZ$$

Parametrization

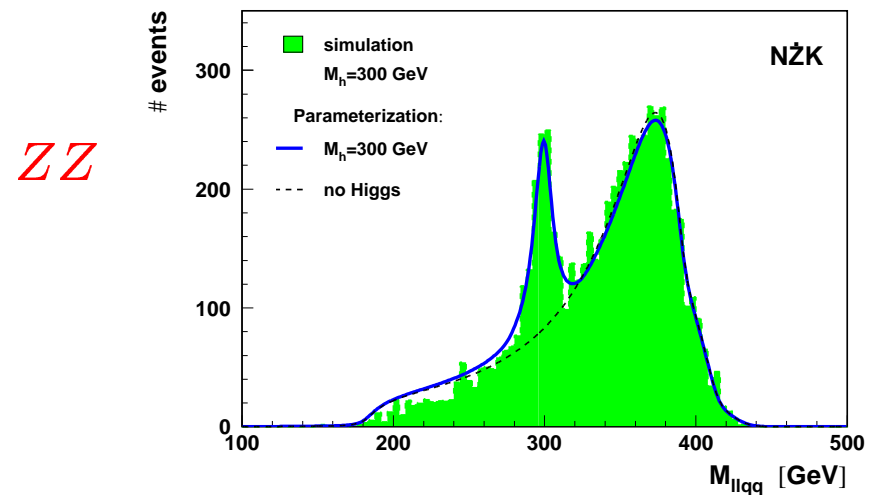
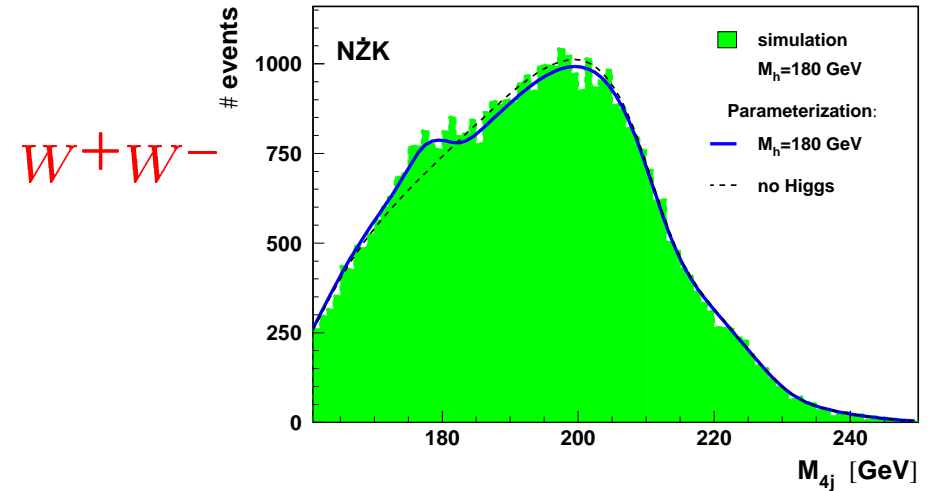
“Measured” invariant mass distribution for selected W^+W^- and ZZ events is described by convolution of:

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

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

⇒ can be used for fast simulation and fitting

Comparison with full simulation:



SM results

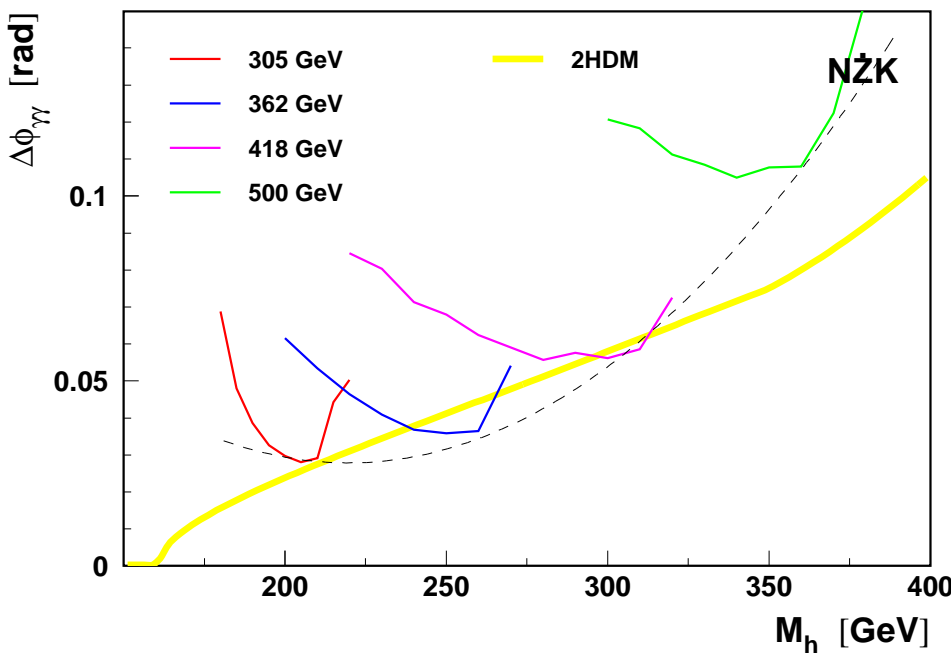
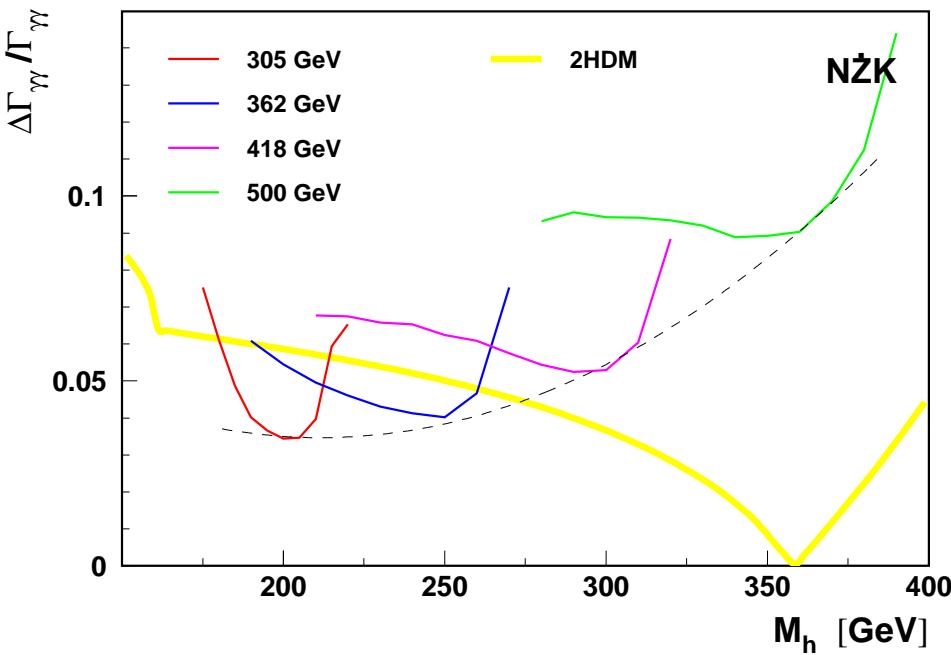
Two parameter fit to W^+W^- and ZZ invariant mass distribution

Expected statistical precision, assuming SM branching ratios (1 PC year):

$\Gamma_{\gamma\gamma}$

hep-ph/0207294

$\phi_{\gamma\gamma}$



Phase measurement significantly improves our sensitivity to new heavy charged particles e.g. heavy charged Higgs boson of the SM-like 2HDM(II) with $M_{H^\pm} = 800$ GeV at large Higgs boson masses

2HDM(II)

SM-like 2HDM(II)

Solution A

For light Higgs boson h :

$$\chi_u = \chi_d = \chi_V = 1$$

χ_i - couplings normalized to SM couplings

All couplings are the same as in SM.

$\Gamma_{\gamma\gamma}$ and $\phi_{\gamma\gamma}$ affected only by the H^+ loop

For heavy Higgs bosons H and A :

$$\chi_V \equiv 0$$

No decays to W^+W^- and ZZ ...

I. F. Ginzburg, M. Krawczyk and P. Osland,
Nucl. Instrum. Meth. A472:149, 2001
hep-ph/0101331; hep-ph/0101208.

Solution B (extended)

	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

$\tan\beta \rightarrow 0 \Rightarrow \text{sol. } B_u$

$\tan\beta \rightarrow \infty \Rightarrow \text{sol. } B_d$

Higgs production ($\Gamma_{\gamma\gamma}$ and $\phi_{\gamma\gamma}$)
and decays depend on $\tan\beta$.

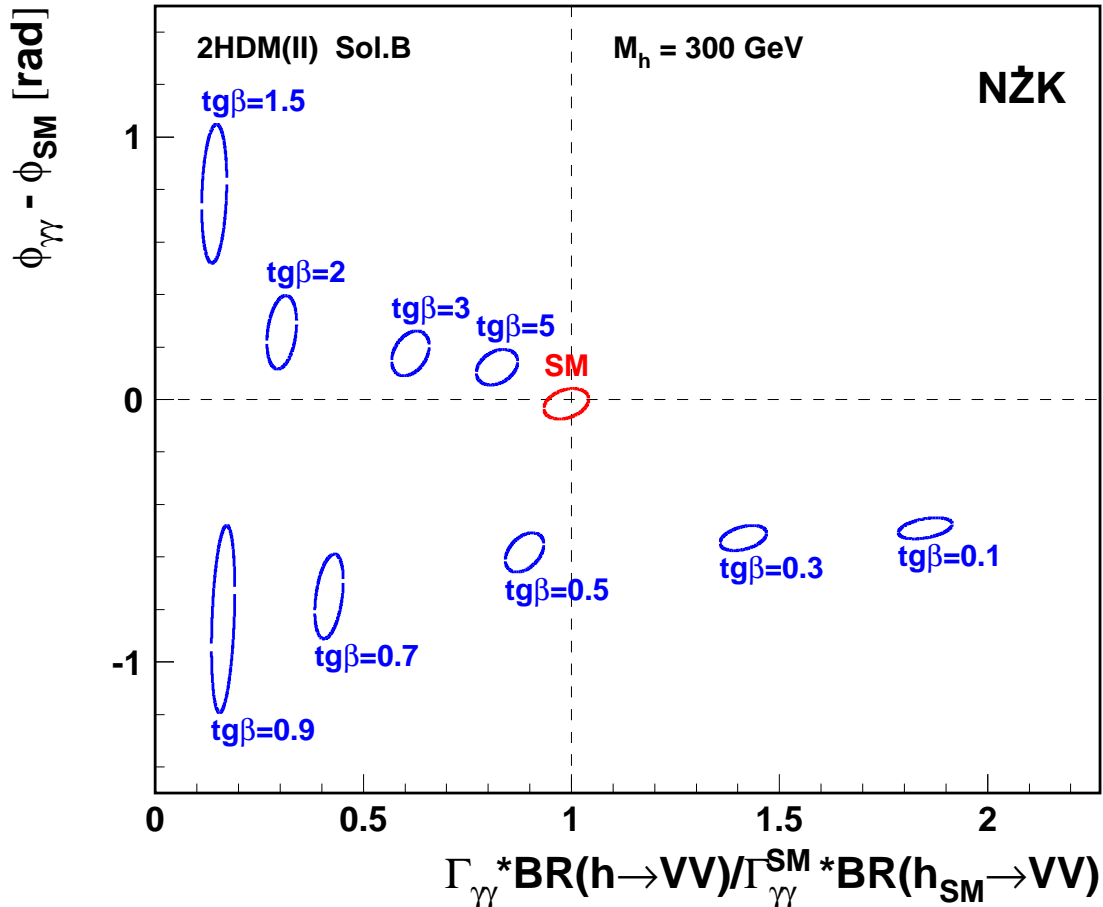
**Can we extract $\tan\beta$ value
from the measured W^+W^- and ZZ
invariant mass distributions ?**

SM-like 2HDM(II)

Light Higgs boson

Two-photon width and phase measurement for different $\tan \beta$ $\chi_V = \cos 2\beta$

$M_h = 300 \text{ GeV}$



Measurement very sensitive to $\tan \beta$
 \Rightarrow precise determination possible.

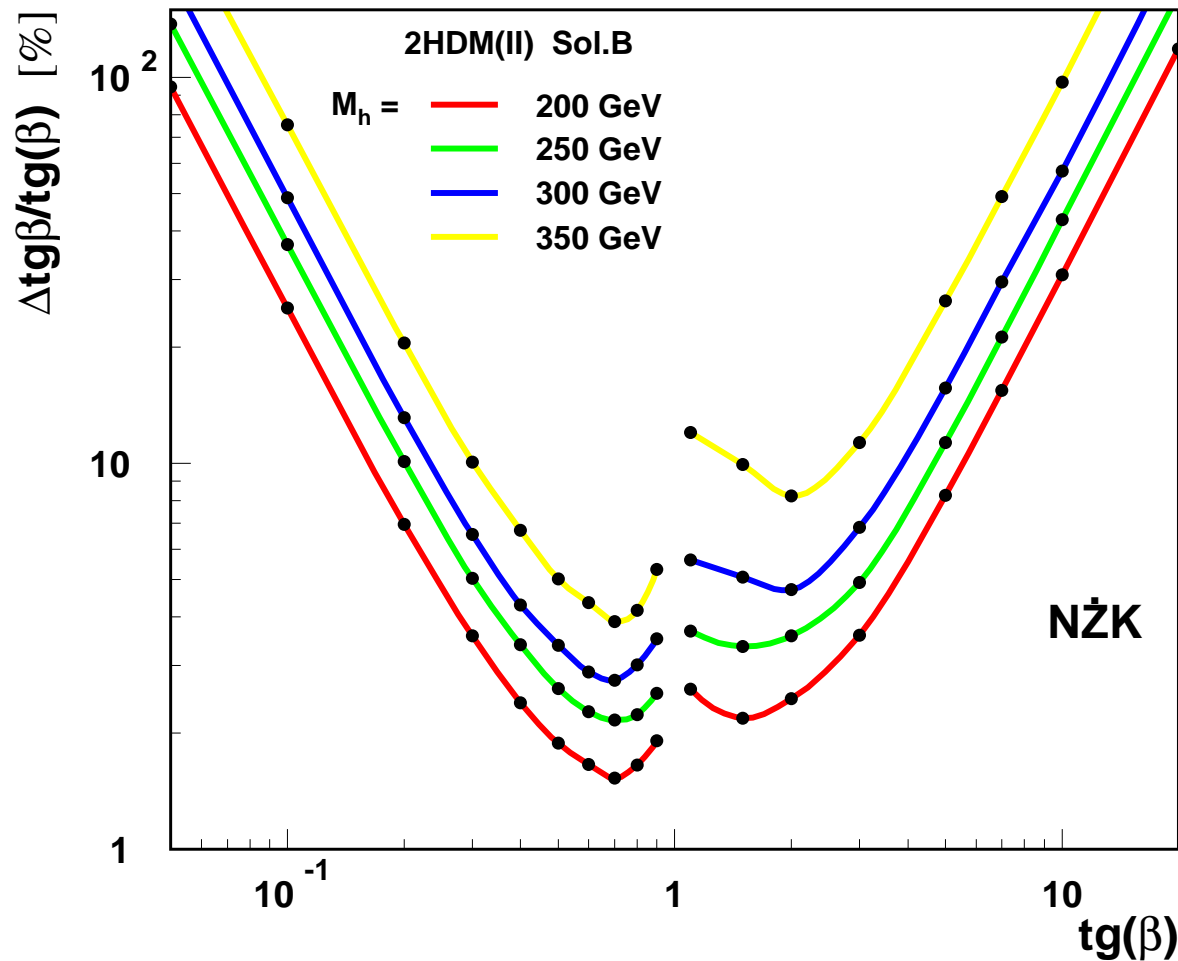
Ambiguity resolved by the phase measurement (distinguishes between low $\tan \beta$ and large $\tan \beta$)

1σ contours for 1 year of PC running
 statistical errors only $M_{H^+} = 800 \text{ GeV}$

SM-like 2HDM(II)

Light Higgs boson

Expected **statistical** precision in $\tan\beta$ determination (1 PC year):



SM-like 2HDM(II)

Light Higgs boson

Influence of **systematic uncertainties** on the $\tan \beta$ determination is estimated by adding additional **free parameters** to the fit:

Uncertainties:

- luminosity
- energy scale
- mass resolution
- luminosity spectra

Parameters:

- ⇒ overall normalization
relative normalization of WW and ZZ samples fixed
- ⇒ Higgs boson mass
- ⇒ Higgs boson width
- ⇒ spectra shape variations

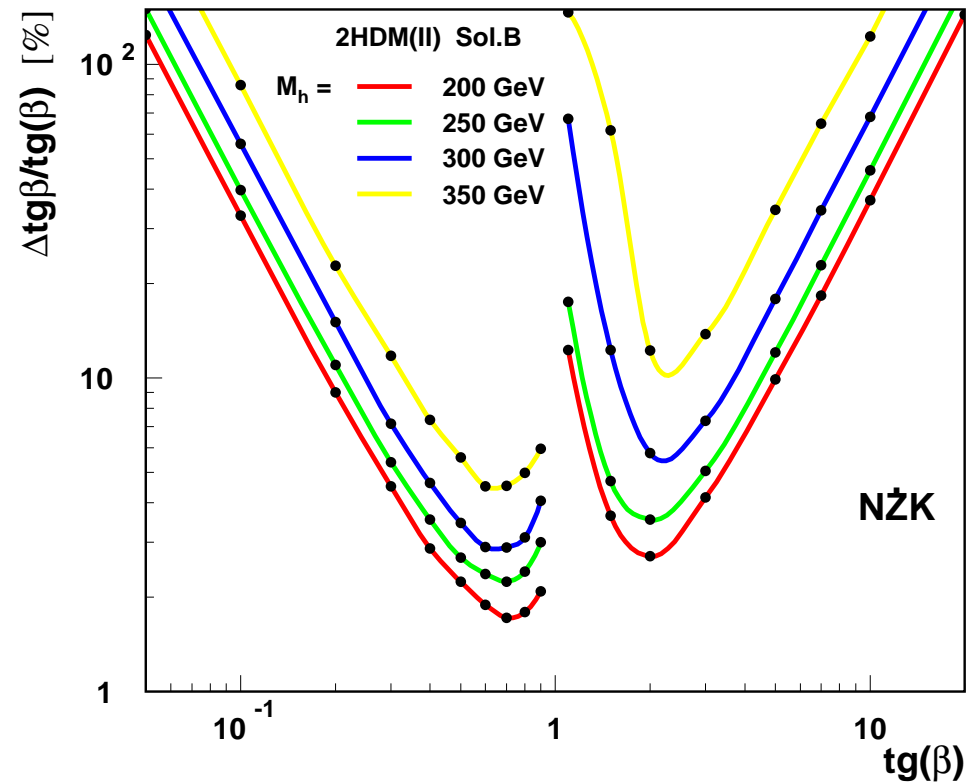
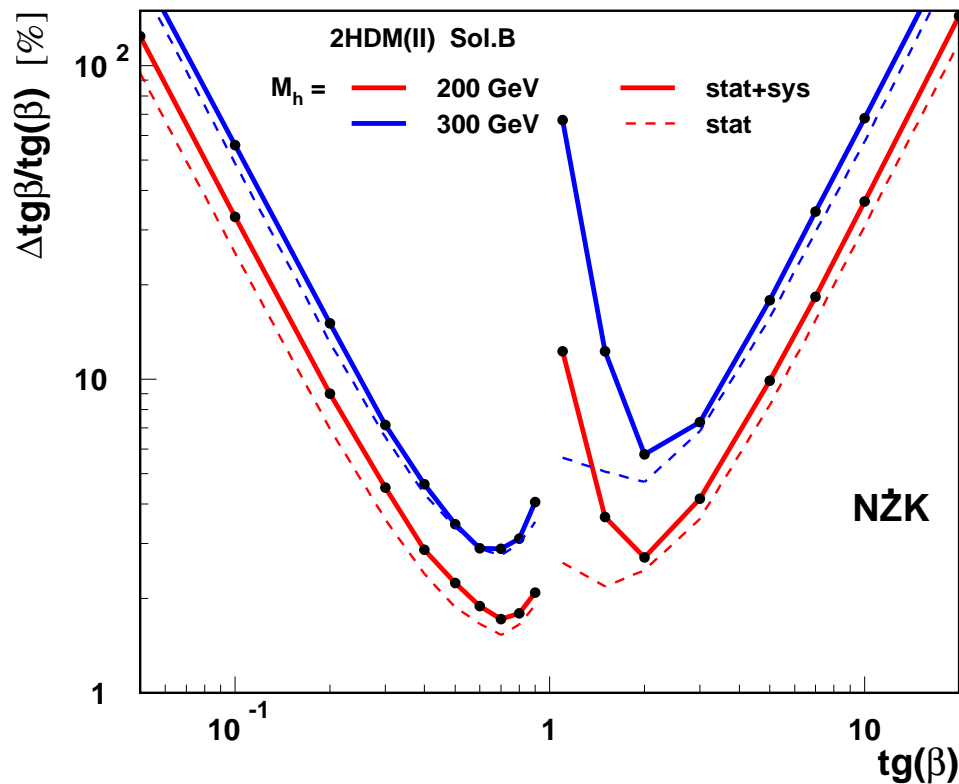
$$\frac{dL}{dW_{\gamma\gamma}} = \frac{dL^{CompAZ}}{dW_{\gamma\gamma}} (1 + A \cdot \sin \pi x + B \cdot \sin 2\pi x)$$
$$x = \frac{W_{\gamma\gamma} - W_{min}}{W_{max} - W_{min}}$$

SM-like 2HDM(II)

Light Higgs boson

Influence of systematic uncertainties
for $M_h = 200$ GeV and $M_h = 300$ GeV

Expected precision in $\tan \beta$ determination
stat. + sys. errors



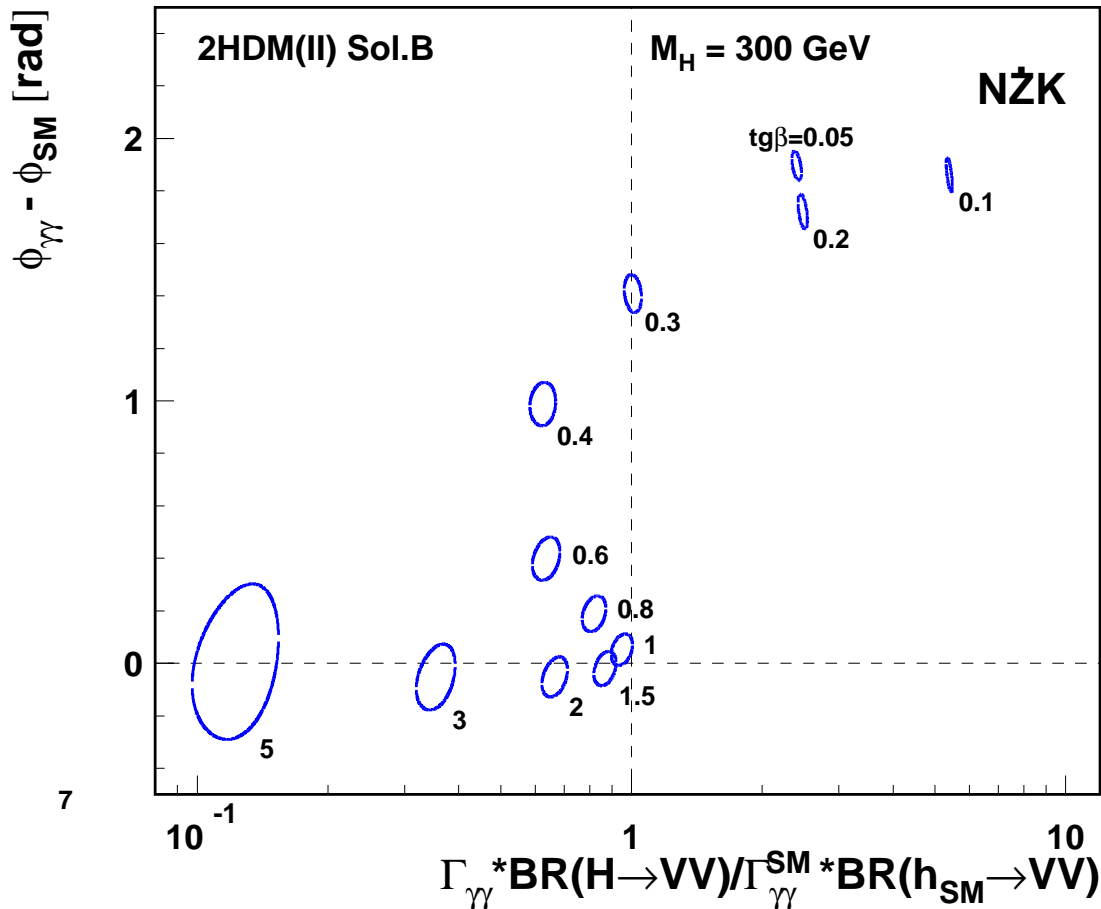
Large effects of systematic uncertainties for $\tan \beta \sim 1$.
For small and large $\tan \beta$ expected error increases by 10–30%.

SM-like 2HDM(II)

Heavy Higgs boson H

Two-photon width and phase measurement for different $\tan \beta$ $\chi_V = -\sin 2\beta$

$M_H = 300 \text{ GeV}$



$\Gamma_{\gamma\gamma}$ enhancement for $\tan \beta < 1$ due to top contribution ($\chi_u = -\frac{1}{\tan \beta}$)

1σ contours for 1 year of PC running
statistical errors only

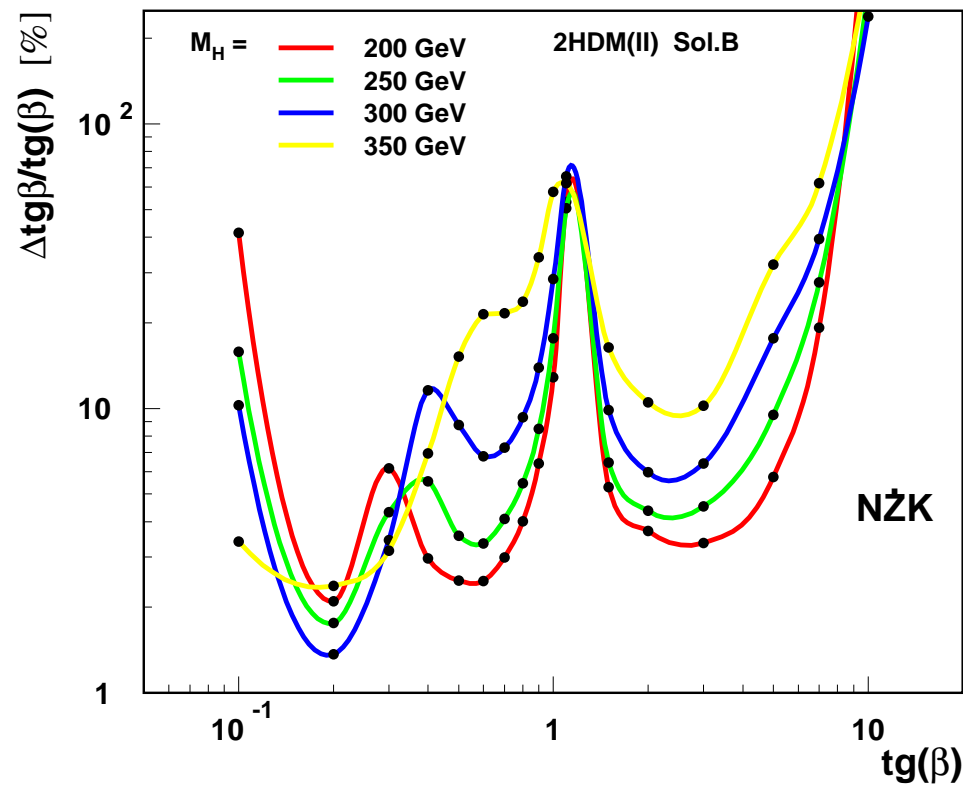
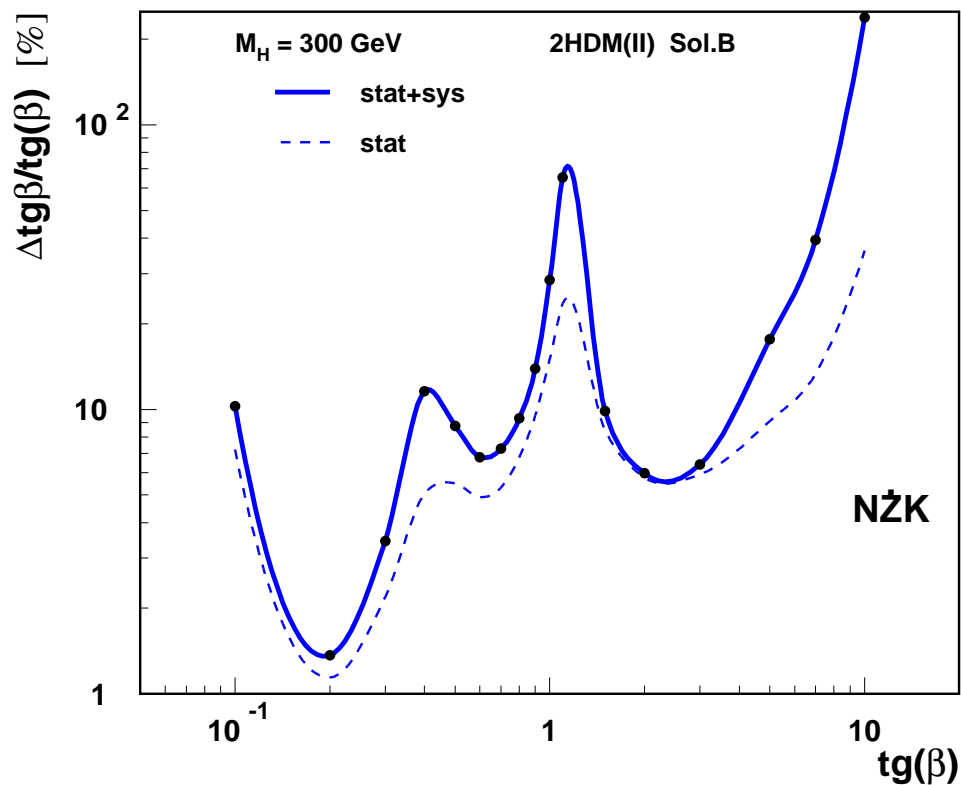
$M_h = 120 \text{ GeV}$, $M_{H^\pm} = 800 \text{ GeV}$

SM-like 2HDM(II)

Heavy Higgs boson H

Influence of systematic uncertainties
for $M_H = 300$ GeV

Expected precision in $\tan\beta$ determination
stat. + sys. errors



Large effects of systematic uncertainties

2HDM(II) with CP violation

General Two Higgs Doublet Model

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 SM-like 2HDM(II) with CP violation through a small mixing between H and A states

Couplings relative to SM: (assuming $|\Phi_{HA}| \ll 1$)

$$\begin{aligned}\chi_X^{h_1} &\approx \chi_X^h \\ \chi_X^{h_2} &\approx \chi_X^H \cdot \cos \Phi_{HA} + \chi_X^A \cdot \sin \Phi_{HA} \\ \chi_X^{h_3} &\approx \chi_X^A \cdot \cos \Phi_{HA} - \chi_X^H \cdot \sin \Phi_{HA}\end{aligned}$$

$$X = u, d \text{ or } V; \quad V = W \text{ or } Z$$

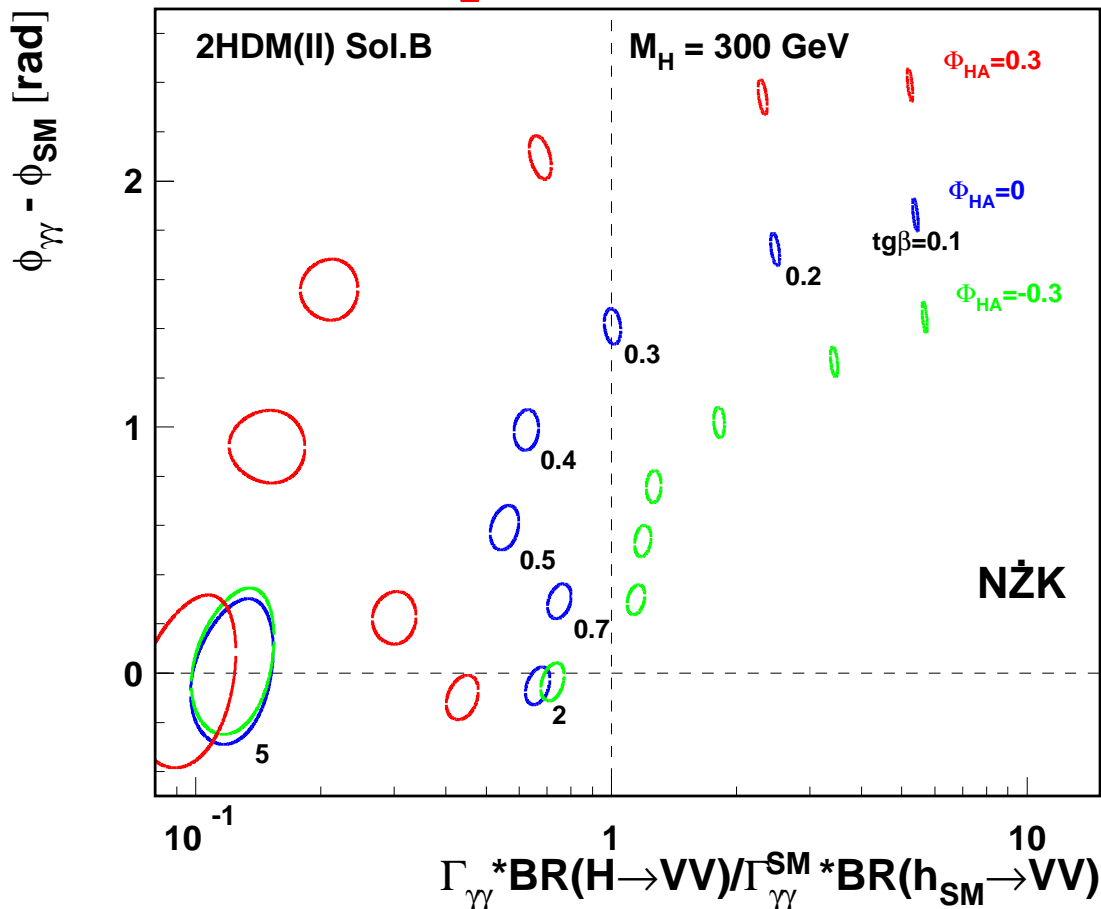
⇒ additional model parameter: **CP-violating mixing phase Φ_{HA}**

2HDM(II) with CP violation

Higgs boson h_2

Two-photon width and phase measurement for different $\tan \beta$ $\Phi_{HA} = 0$

$$M_{h_2} = 300 \text{ GeV}$$



Low $\tan \beta$

\Rightarrow large effects due to H-A mixing

Large $\tan \beta$

\Rightarrow little sensitivity to Φ_{HA}

1σ contours for 1 year of PC running
statistical errors only

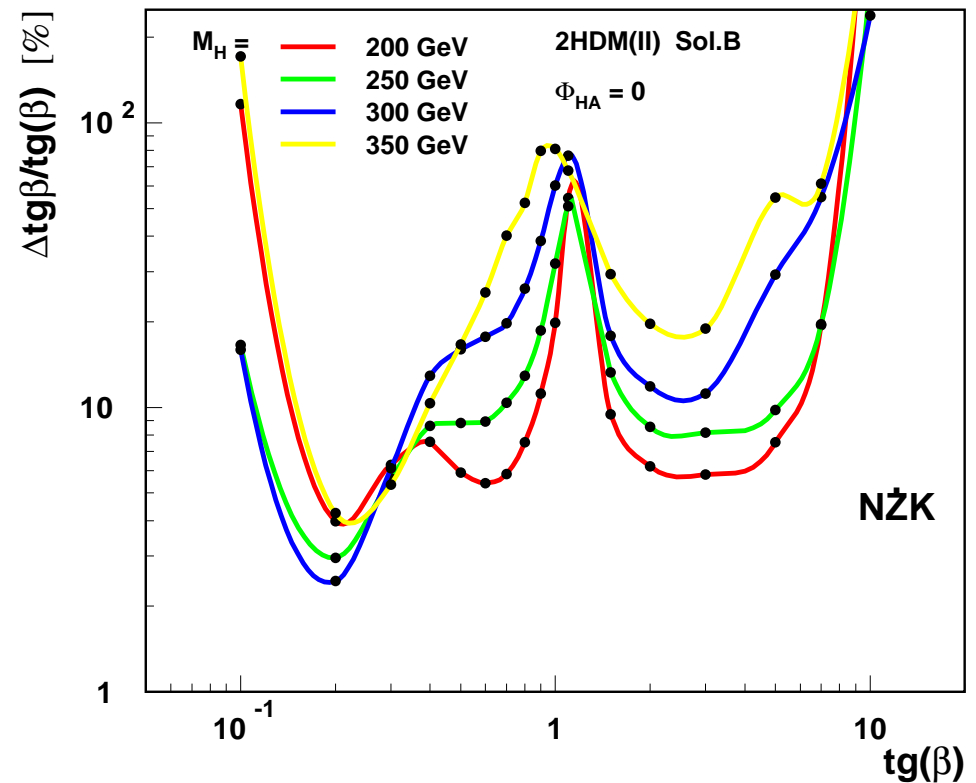
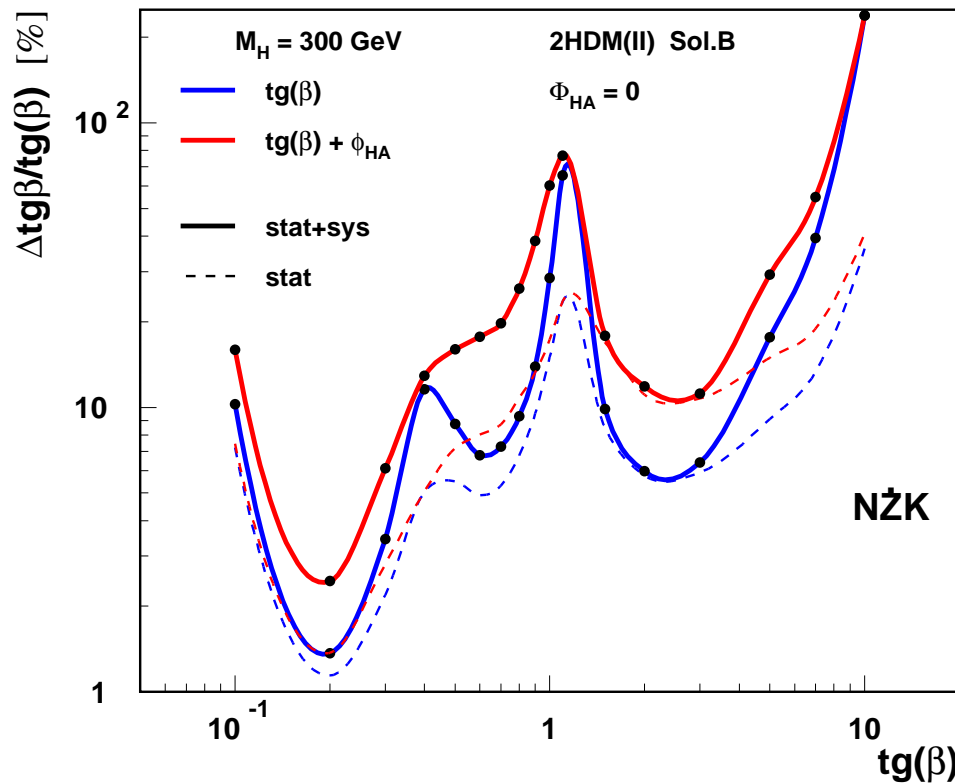
$$M_h = 120 \text{ GeV}, M_{H^+} = 800 \text{ GeV}$$

2HDM(II) with CP violation

Higgs boson h_2

Influence of phase and systematics in $\tan\beta$ determination ($M_H = 300$ GeV)

Expected precision in $\tan\beta$ determination stat. + sys. errors from $\tan\beta$ and Φ_{HA} fit



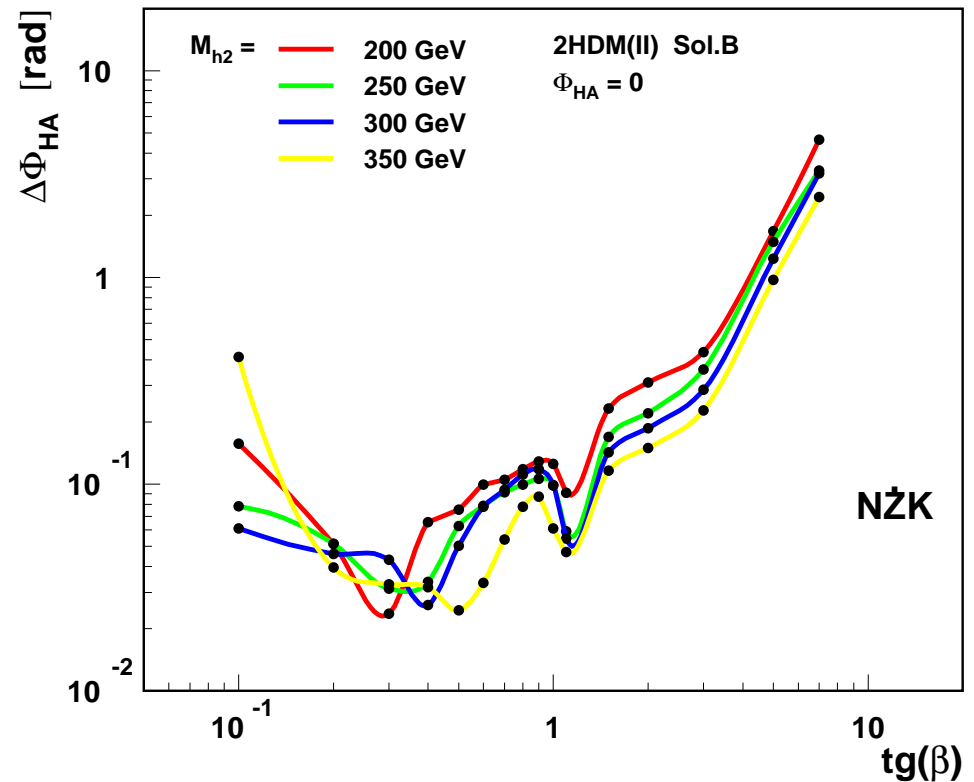
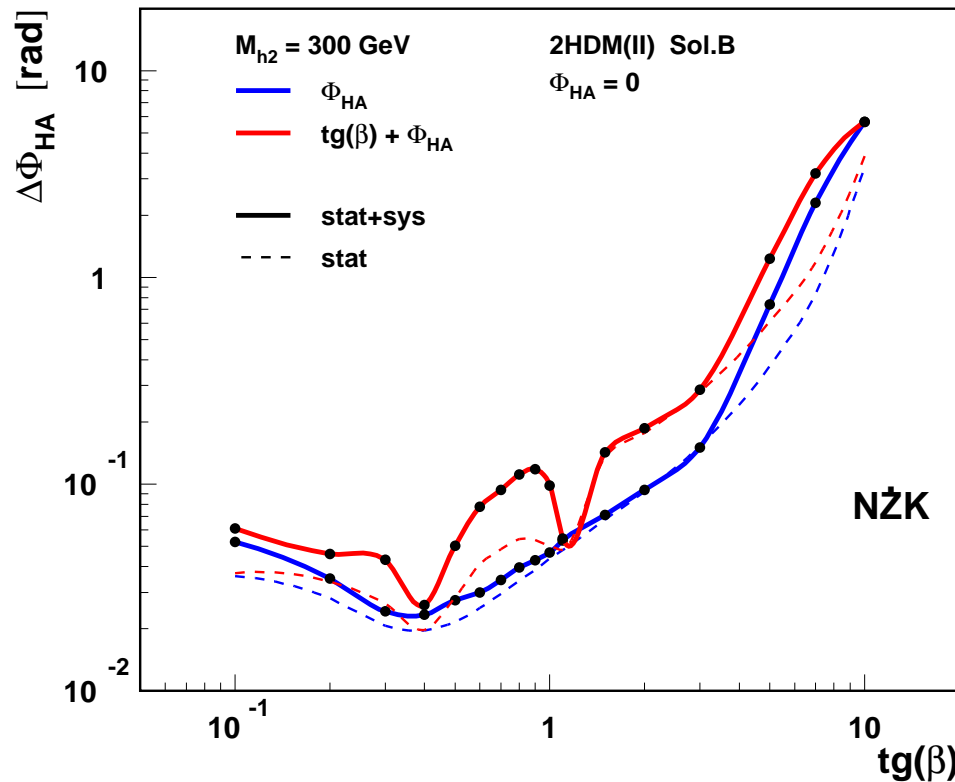
Possible CP violation increases expected $\tan\beta$ measurement errors

2HDM(II) with CP violation

Higgs boson h_2

Influence of $\tan\beta$ and systematics in Φ_{HA} measurement ($M_{H_2} = 300$ GeV, $\Phi_{HA} = 0$)

Expected precision in Φ_{HA} determination stat. + sys. errors from $\tan\beta$ and Φ_{HA} fit



CP violating H–A mixing can be precisely measured if $\tan\beta$ is not too large

Generic model

Couplings

We consider model with a **generic tensor couplings** of a Higgs boson \mathcal{H} , to ZZ and W^+W^- :

$$g_{\mathcal{H}ZZ} = ig \frac{M_Z}{\cos \theta_W} \left(\lambda_H \cdot g^{\mu\nu} + \lambda_A \cdot \varepsilon^{\mu\nu\rho\sigma} \frac{(p_1 + p_2)_\rho (p_1 - p_2)_\sigma}{M_Z^2} \right)$$
$$g_{\mathcal{H}WW} = ig M_W \left(\lambda_H \cdot g^{\mu\nu} + \lambda_A \cdot \varepsilon^{\mu\nu\rho\sigma} \frac{(p_1 + p_2)_\rho (p_1 - p_2)_\sigma}{M_W^2} \right)$$

Standard Model (scalar) couplings are reproduced for $\lambda_H = 1$ and $\lambda_A = 0$.

Pseudoscalar Higgs boson corresponds to $\lambda_H = 0$ and $\lambda_A = 1$.

We consider **small CP violation** (deviations from SM), i.e. $\lambda_H \sim 1$, $|\lambda_A| \ll 1$

\mathcal{H} couplings to fermions assumed to be the same as in the **Standard Model**.

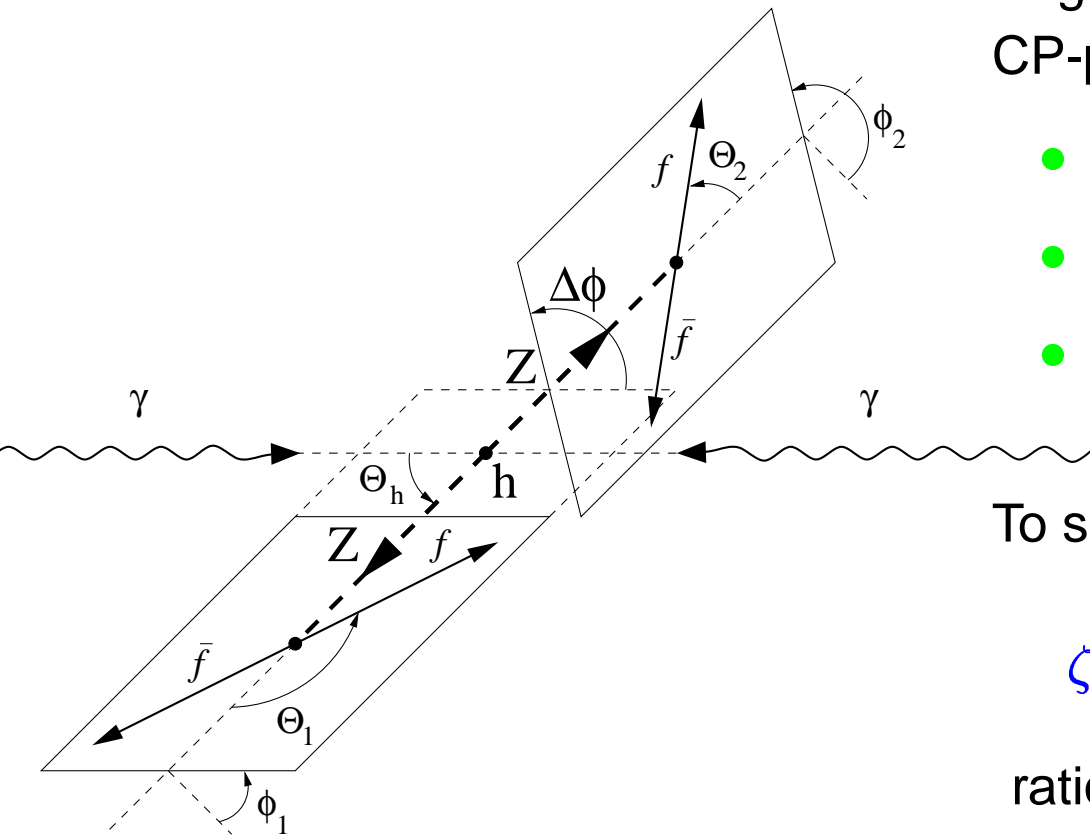
Model: S.Y. Choi, D.J. Miller, M.M. Mühlleitner and P.M. Zerwas, hep-ph/0210077;
D.J. Miller, S.Y. Choi, B. Eberle, M.M. Mühlleitner and P.M. Zerwas, Phys. Lett. B505 (2001) 149;
D.J. Miller, *Spin and Parity in the HZZ vertex*, ECFA/DESY meeting, Prague, November 2002.

Higgs CP from $\mathcal{H} \rightarrow \tau^+\tau^-$: K. Desch, A. Imhof, Z. Was, M. Worek, hep-ph/0307331;
K. Desch, Z. Was, M. Worek, Eur.Phys.J.C29 (2003) 491, hep-ph/0302046.

Higgs CP from $\mathcal{H} \rightarrow t\bar{t}$: E. Asakawa, K. Hagiwara, hep-ph/0305323.

Generic model

Angular distributions



Angular variables used in the analysis of higgs CP-properties:

- higgs decay angle Θ_h
- polar angles Θ_1 and Θ_2
- angle between two Z/W decay planes,

$$\Delta\phi = \phi_2 - \phi_1$$

To simplify the analysis, we introduce

$$\zeta = \frac{\sin^2 \Theta_1 \cdot \sin^2 \Theta_2}{(1 + \cos^2 \Theta_1) \cdot (1 + \cos^2 \Theta_2)}$$

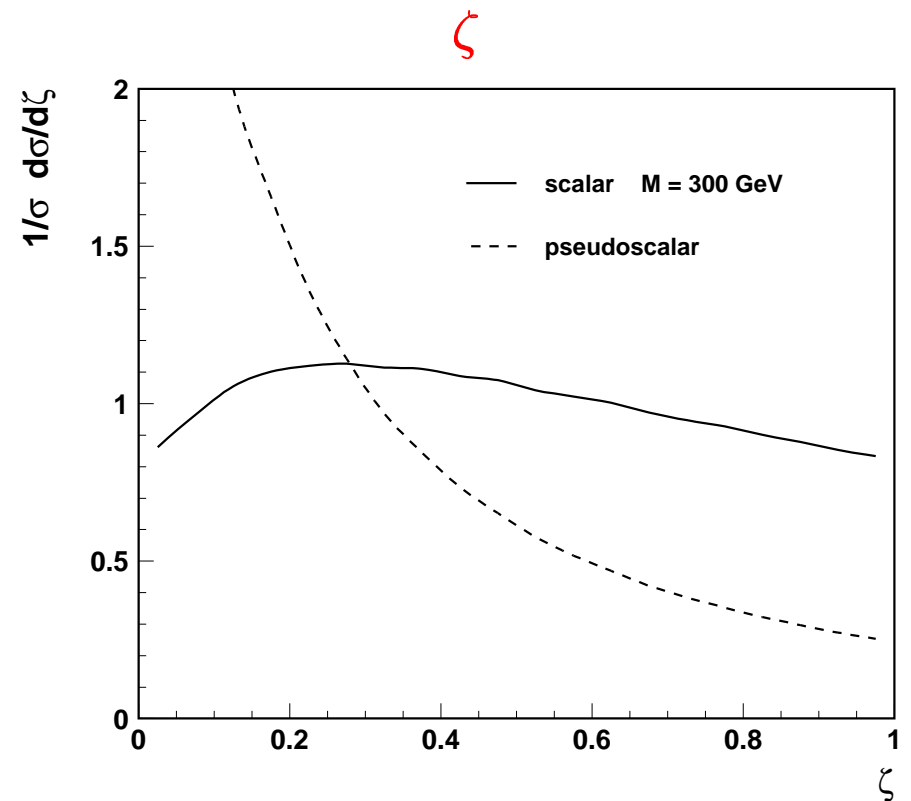
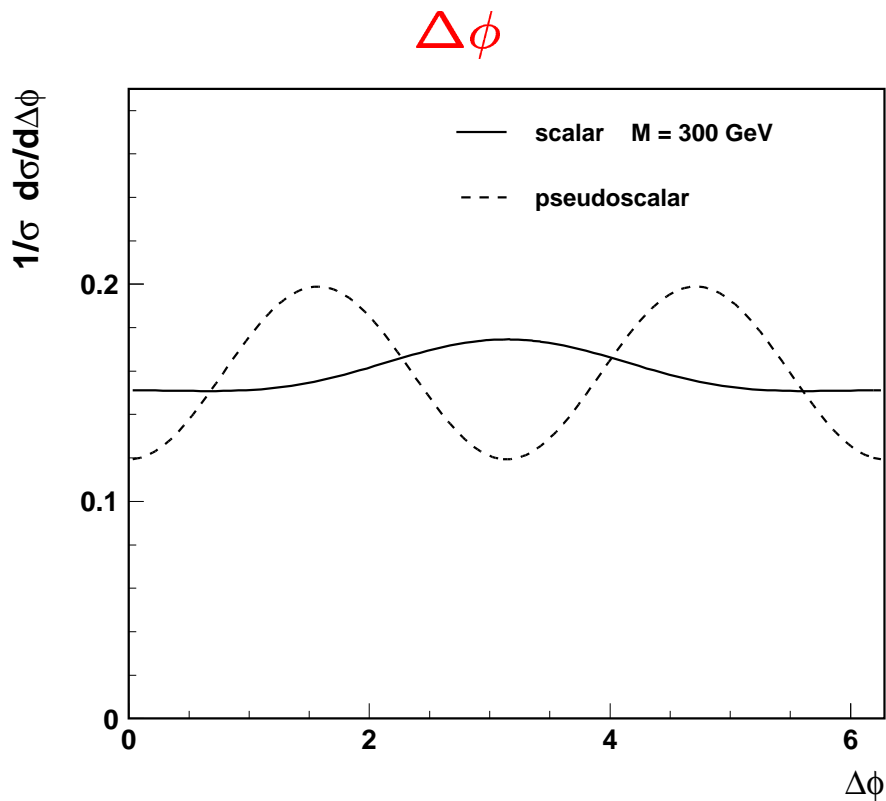
ratio of the distributions expected for a scalar and a pseudoscalar higgs (for $M_h \gg M_Z$).

All polar angles are calculated in the rest frame of the decaying particle.

Generic model

Angular distributions

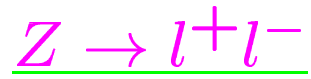
Normalized angular distributions expected for **scalar** and **pseudoscalar** higgs, for $\mathcal{H} \rightarrow ZZ \rightarrow l^+l^-jj$ $M_{\mathcal{H}} = 300$ GeV.



Both distributions clearly distinguish between decays of scalar and pseudoscalar higgs.

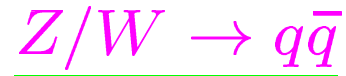
Generic model

Expected accuracy of decay angles measurement:



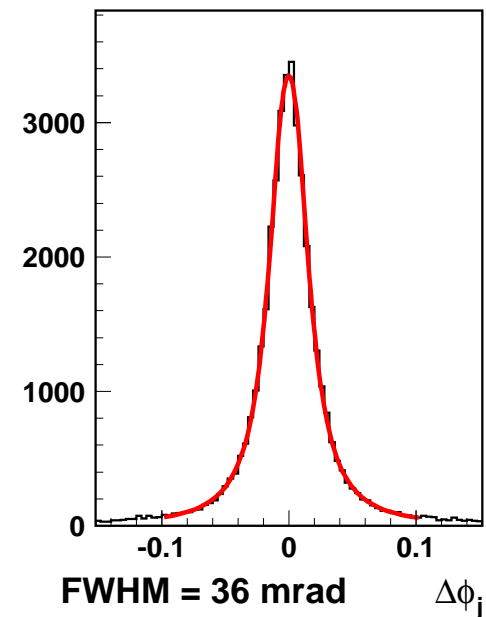
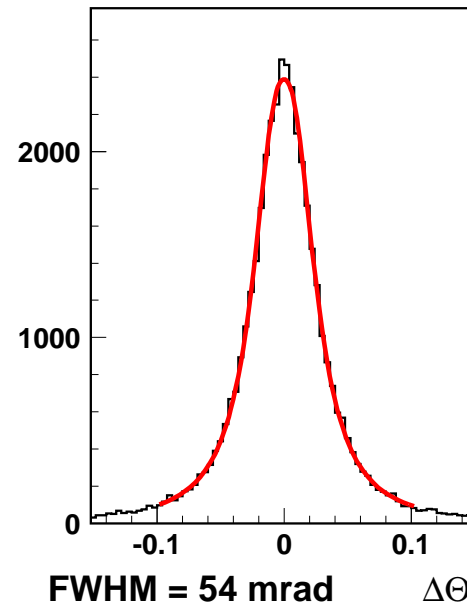
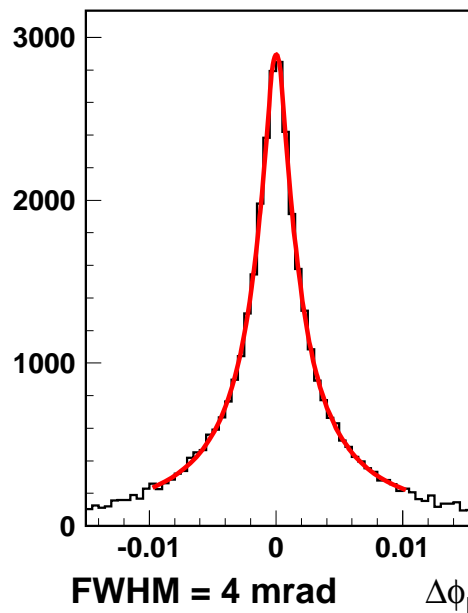
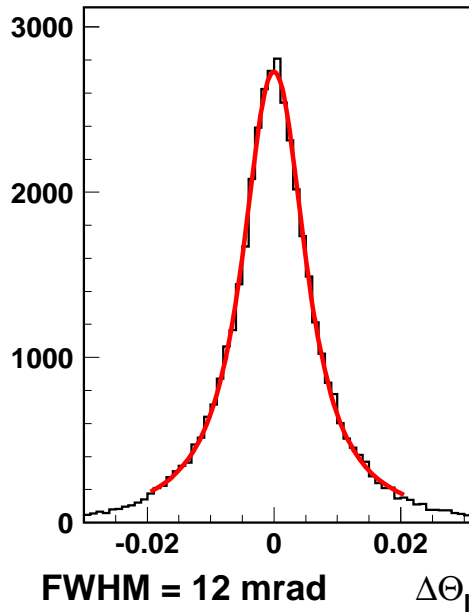
polar angle θ_l

azimuthal angle ϕ_l



polar angle θ_q

azimuthal angle ϕ_q



\sim same for $\Delta\phi$

All angles can be measured with high accuracy

Shape described by Breit-Wigner distribution

Generic model

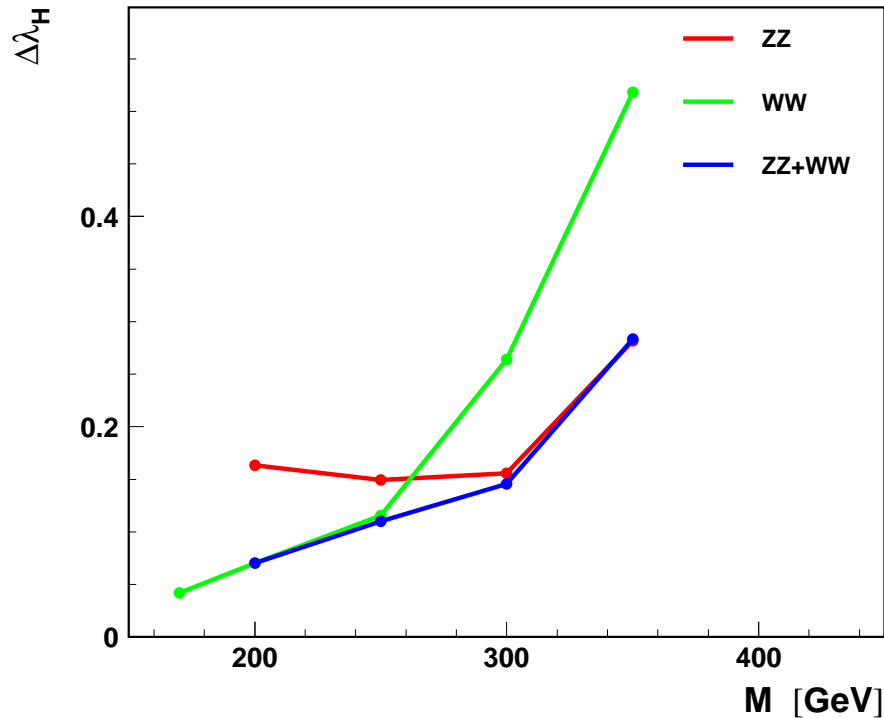
Preliminary

EPS'2003

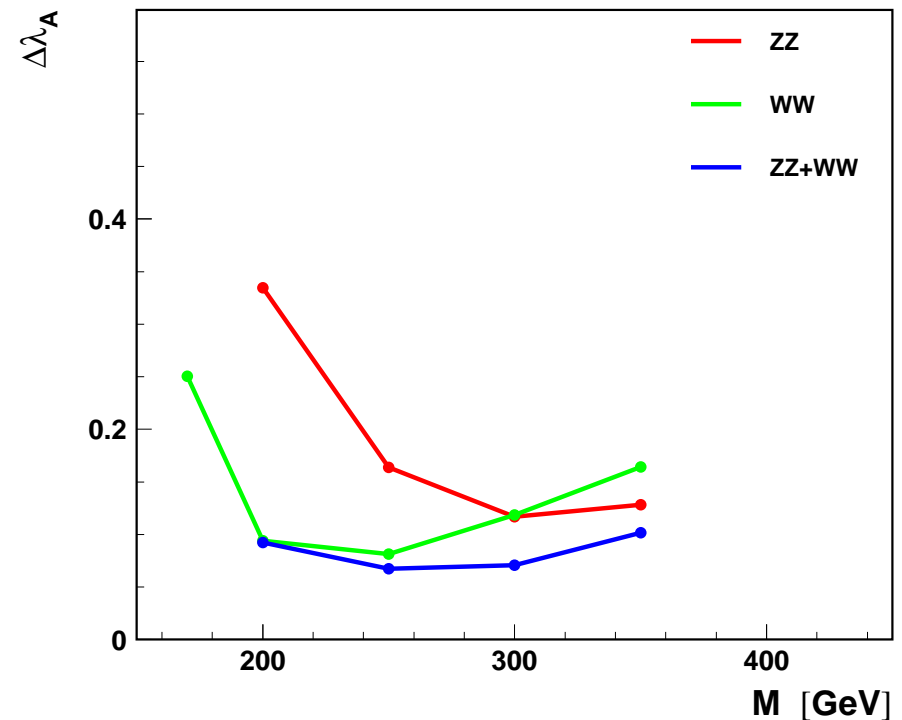
Combined measurement of angular correlations in the W^+W^- and ZZ -decay products

Measurement error for Higgs-boson couplings to vector bosons:

scalar



pseudoscalar



assuming SM-like couplings: $\lambda_H = 1$ $\lambda_A = 0$

Summary

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

Mass range $200 < M_{\mathcal{H}} < 350$ GeV considered.

Strong dependence on Higgs boson couplings is expected for SM-like 2HDM (II) sol. B

Both h and H boson decays can be used for precise determination of $\tan \beta$.

Precision better than 10% is obtained in wide parameter range.

CP violating H–A mixing phase Φ_{HA} can be measured

with precision $\Delta\Phi_{HA} \leq 0.1$ rad, for $\tan \beta < 1$

From combined measurement of angular correlations in the W^+W^- and ZZ decays CP violation in the higgs couplings to vector bosons can be determined to about 10%.

Analysis still ongoing...