Determination of the Higgs-boson couplings from WW/ZZ decays in CP-conserving 2HDM (II)

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NŻK

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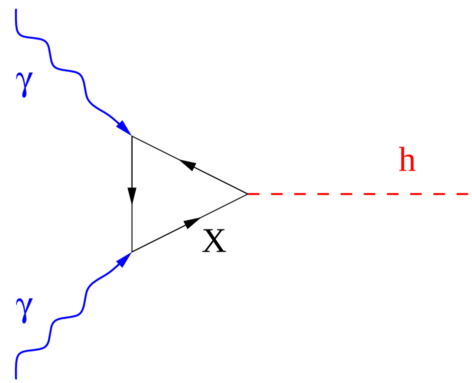
- Higgs boson production and decays to WW and ZZ at PLC
  JHEP 0211 (2002) 034 [hep-ph/0207294]
  measurement of $\Gamma_{\gamma\gamma}$ and $\phi_{\gamma\gamma}$
- Results for SM-like 2HDM(II) scenario B_h
  hep-ph/0403138
- Results for general 2HDM(II)
- Comparison with LHC and LC

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

Higgs boson production at the Photon Collider

Production cross section is proportional to the two-photon width



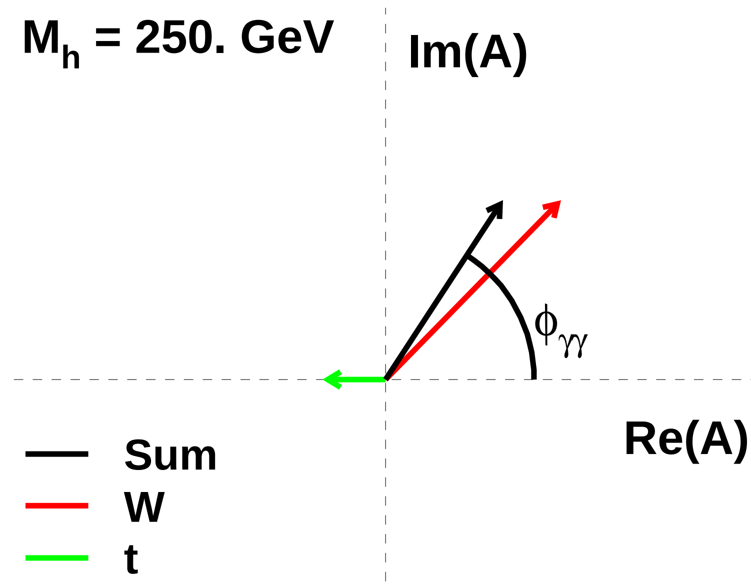
$$\Gamma(h \to \gamma\gamma) \;=\; \frac{G_F \alpha^2 M_h^3}{128\sqrt{2}\,\pi^3} \cdot |\mathcal{A}|^2$$

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.



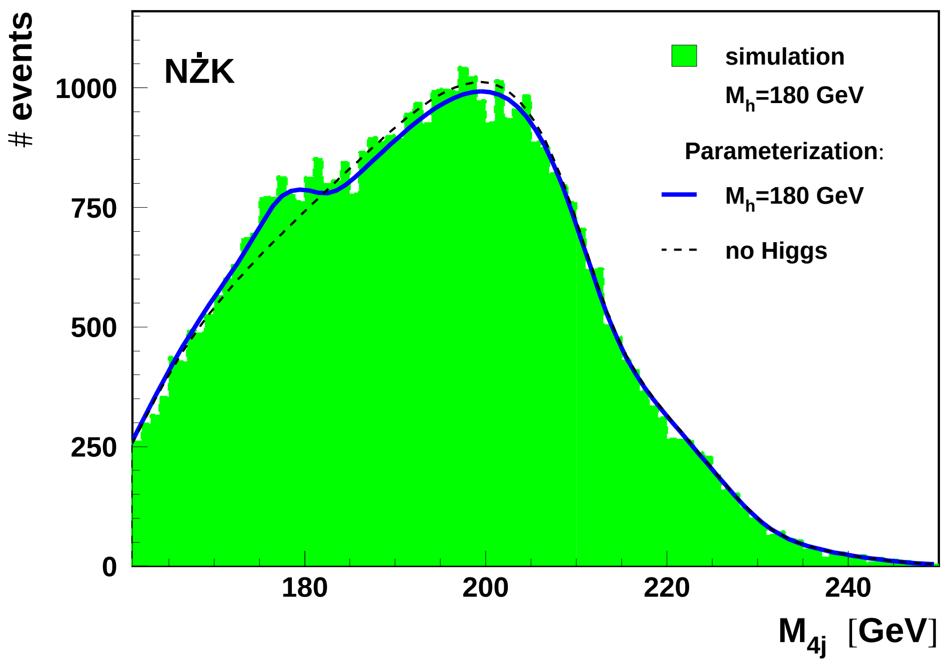
Phases of $W^\pm$ and top contributions differ !

Both $\Gamma_{\gamma\gamma}$ and the phase of the amplitude $\phi_{\gamma\gamma}$ depend on Higgs-boson couplings !

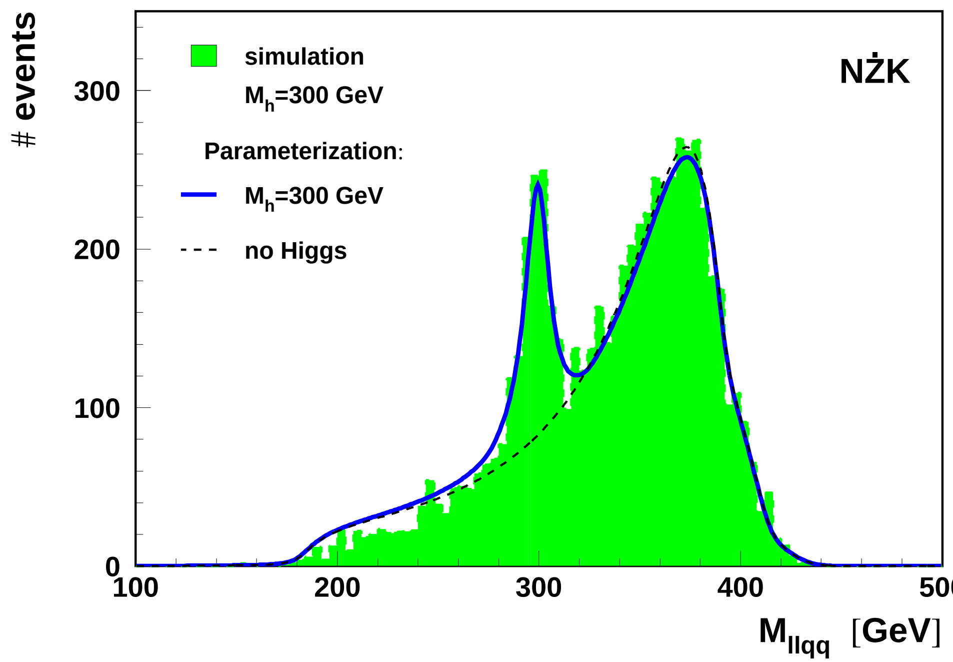
$$\gamma\gamma \to \mathcal{H} \to WW,\ ZZ$$

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.

W^+W^-



ZZ



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

JHEP 0211 (2002) 034 [hep-ph/0207294]

A.F.Żarnecki, ECFA/DESY workshop, November 2002, Praha (including systematic uncertainties)

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_h

	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

$\tan\beta \to 0 \ \Rightarrow$ sol. B_u

$\tan\beta \to \infty \Rightarrow$ sol. B_d

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

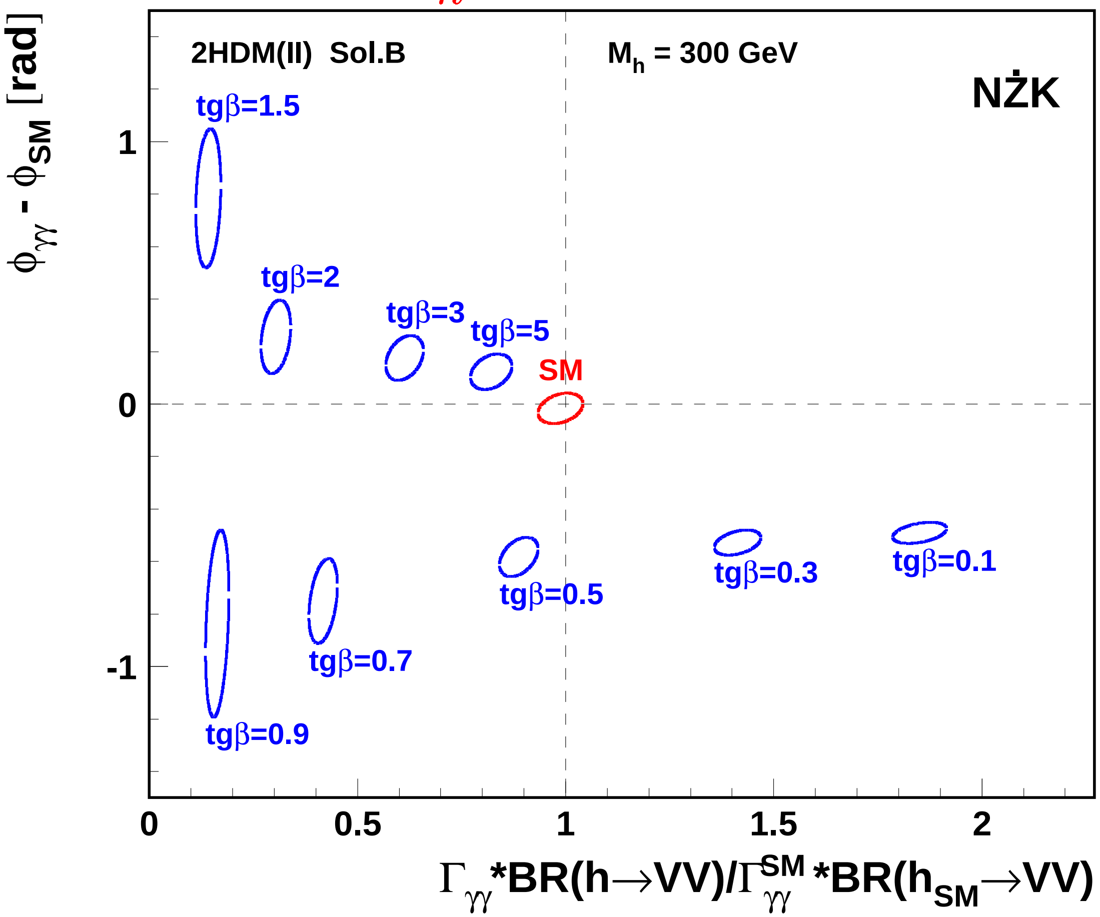
Can we extract $\tan\beta$ value
from the measured W^+W^- and ZZ
invariant mass distributions ?

SM-like 2HDM(II)

Light Higgs boson h

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

M_h = 300 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

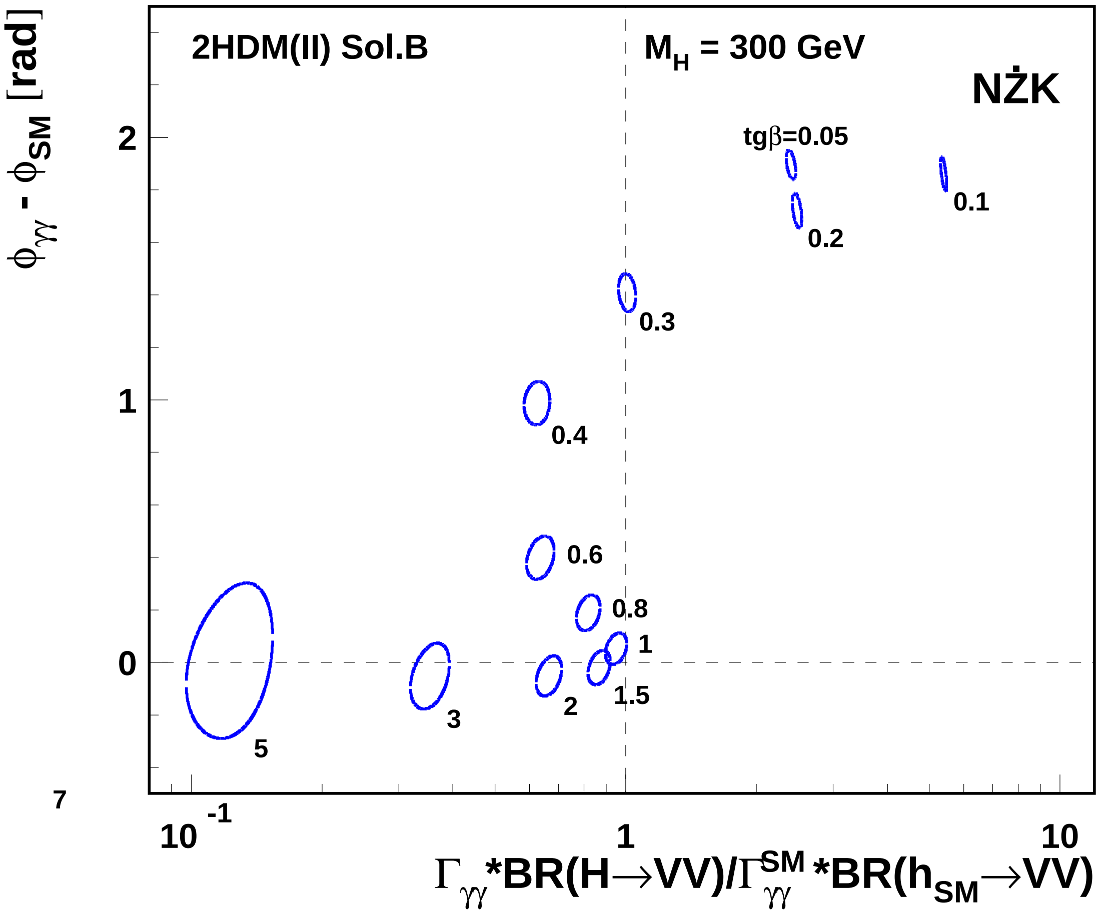
statistical errors only M_{H+}=800 GeV

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 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

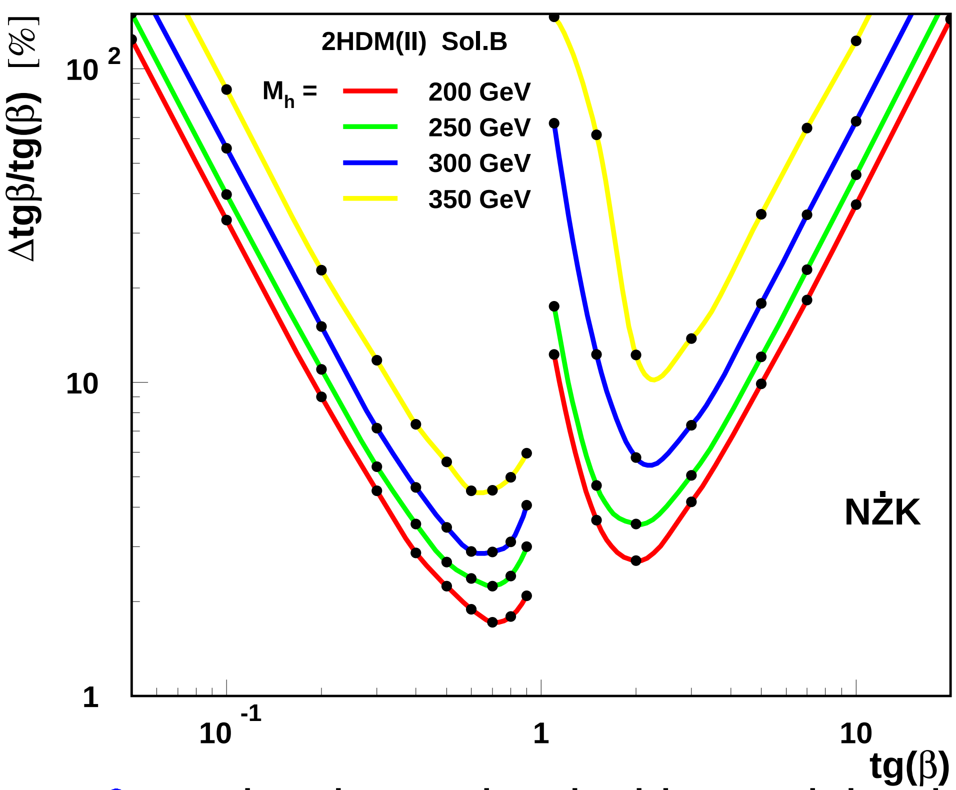
M_h=120 GeV, M_{H+}=800 GeV

SM-like 2HDM(II)

Light Higgs boson h

Expected precision in $\tan\beta$ determination

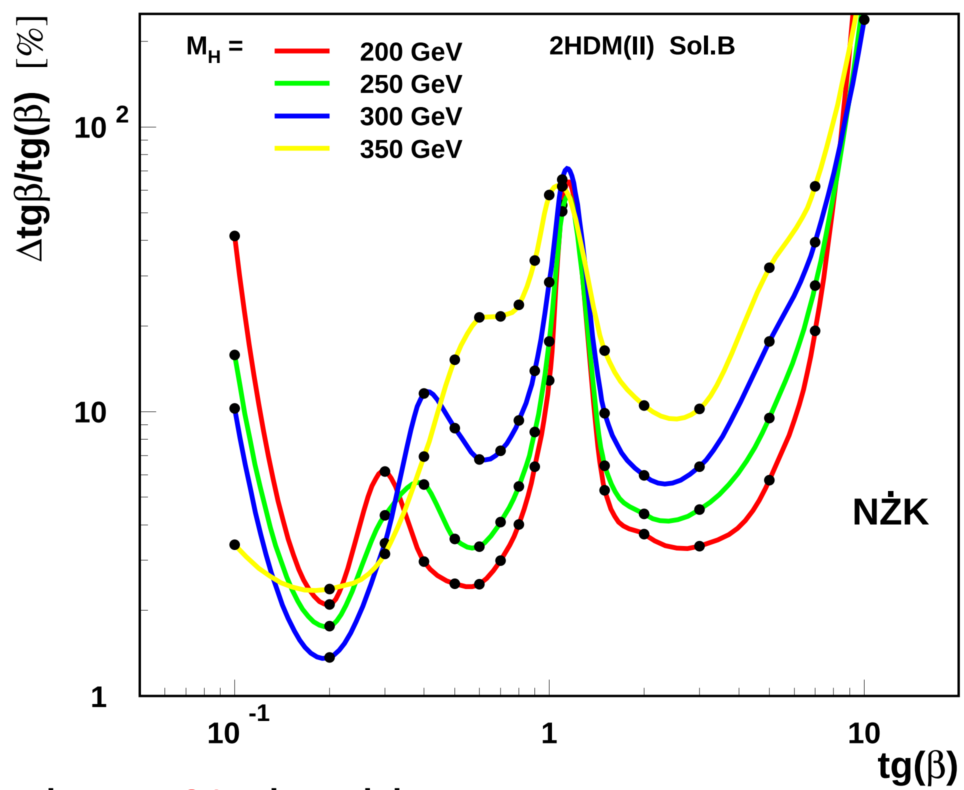
stat. + sys. errors



Heavy Higgs boson H

Expected precision in $\tan\beta$ determination

stat. + sys. errors



$\tan\beta$ can be determined with precision better than 10% in wide parameter range

General 2HDM (II)

Higgs boson couplings

We consider scalar Higgs bosons h and H in the CP-conserving Two Higgs Doublet Model.

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	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$-i\,\gamma_5\,\frac{1}{\tan\beta}$
χ_d	$-\frac{\sin\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$-i\,\gamma_5\,\tan\beta$
χ_V	$\sin(\beta-\alpha)$	$\cos(\beta-\alpha)$	0

For charged Higgs boson couplings (loop contribution to $\Gamma_{\gamma\gamma}$) we set

$$M_{H^\pm} = 800\ GeV \qquad \mu = 0$$

Higgs couplings are related by "patter relation"

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

Instead of angles α and β we use couplings χ_V and χ_u to parametrize cross sections and BRs.

As the overall sign of Higgs couplings does not matter we choose

$$0 \leq \chi_V \leq 1$$

If we neglect H decays to h and A (small) cross sections and BRs calculated for H are also valid for h

General 2HDM (II)

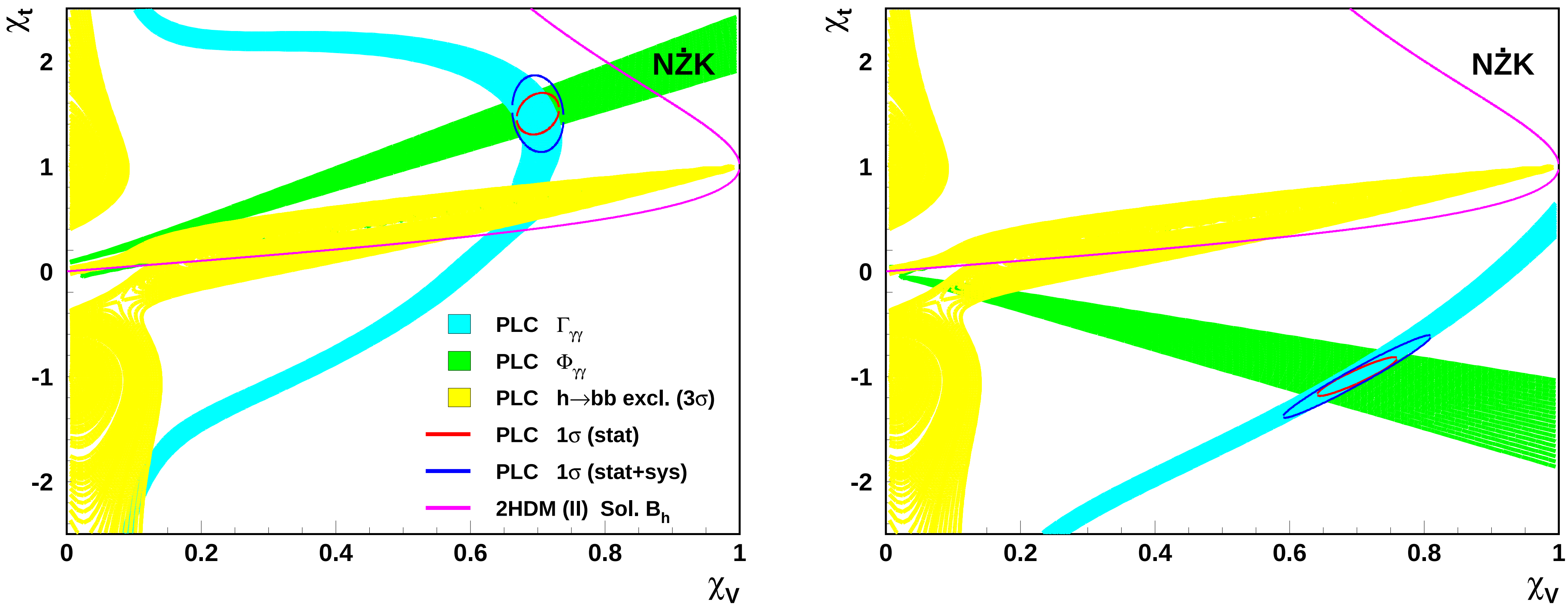
Combined fit to W^+W^- and ZZ invariant mass distributions

$\Rightarrow$ two-photon width $\Gamma_{\gamma\gamma}$ and phase $\phi_{\gamma\gamma}$

$\Rightarrow$ couplings to both vector bosons (χ_v) and up fermions (χ_t) can be determined

1σ contours for 1 year of PC running, $M_H = 300$ GeV

$\chi_v = 0.7 \quad \chi_t = 1.5 \qquad\qquad \chi_v = 0.7 \quad \chi_t = -1$

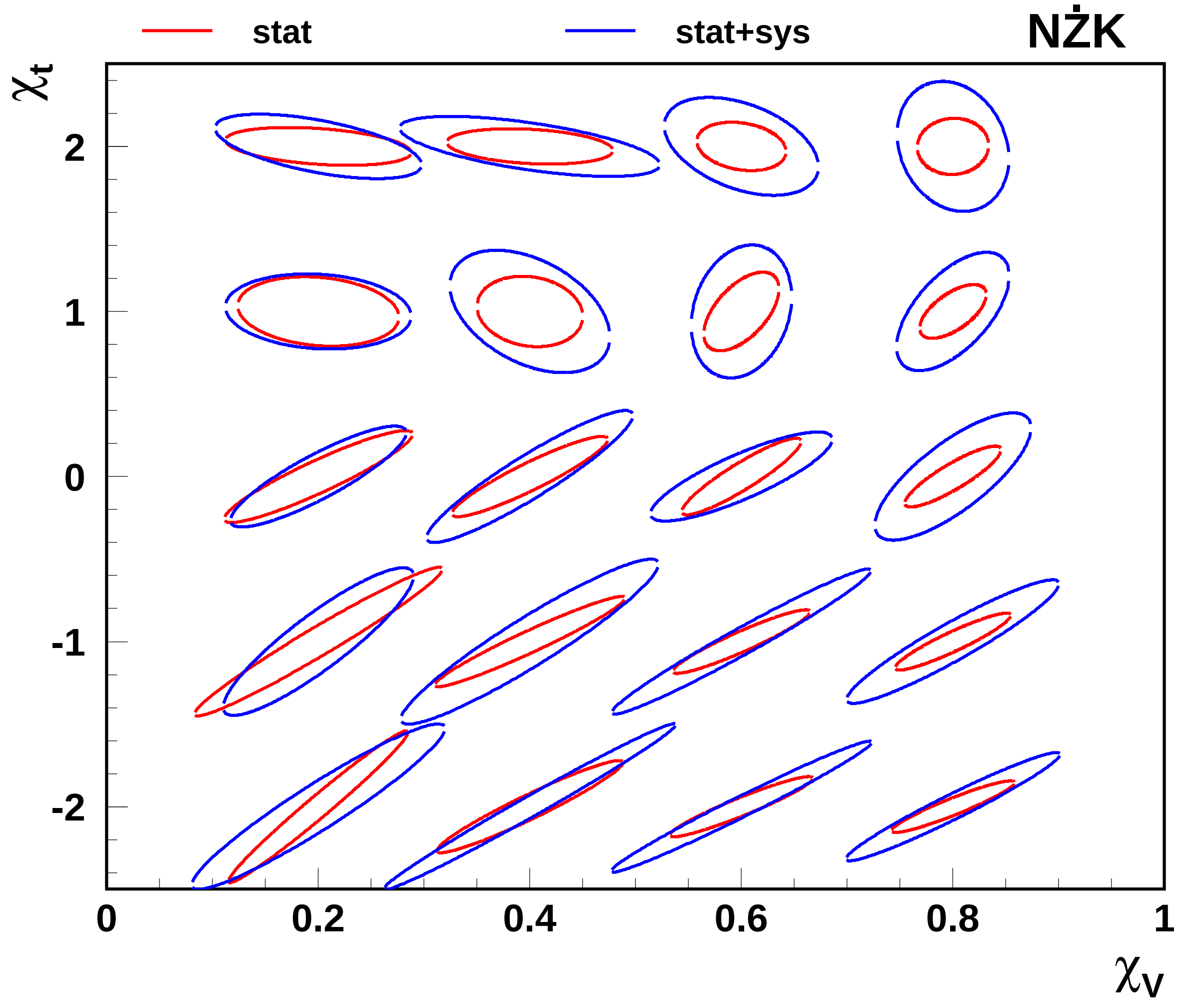


General 2HDM (II)

H couplings to vector bosons (χ_v) and up fermions (χ_t) from combined fit to W^+W^- and ZZ invariant mass distributions

Comparison of estimated statistical and total (stat+sys) errors of the measurement.

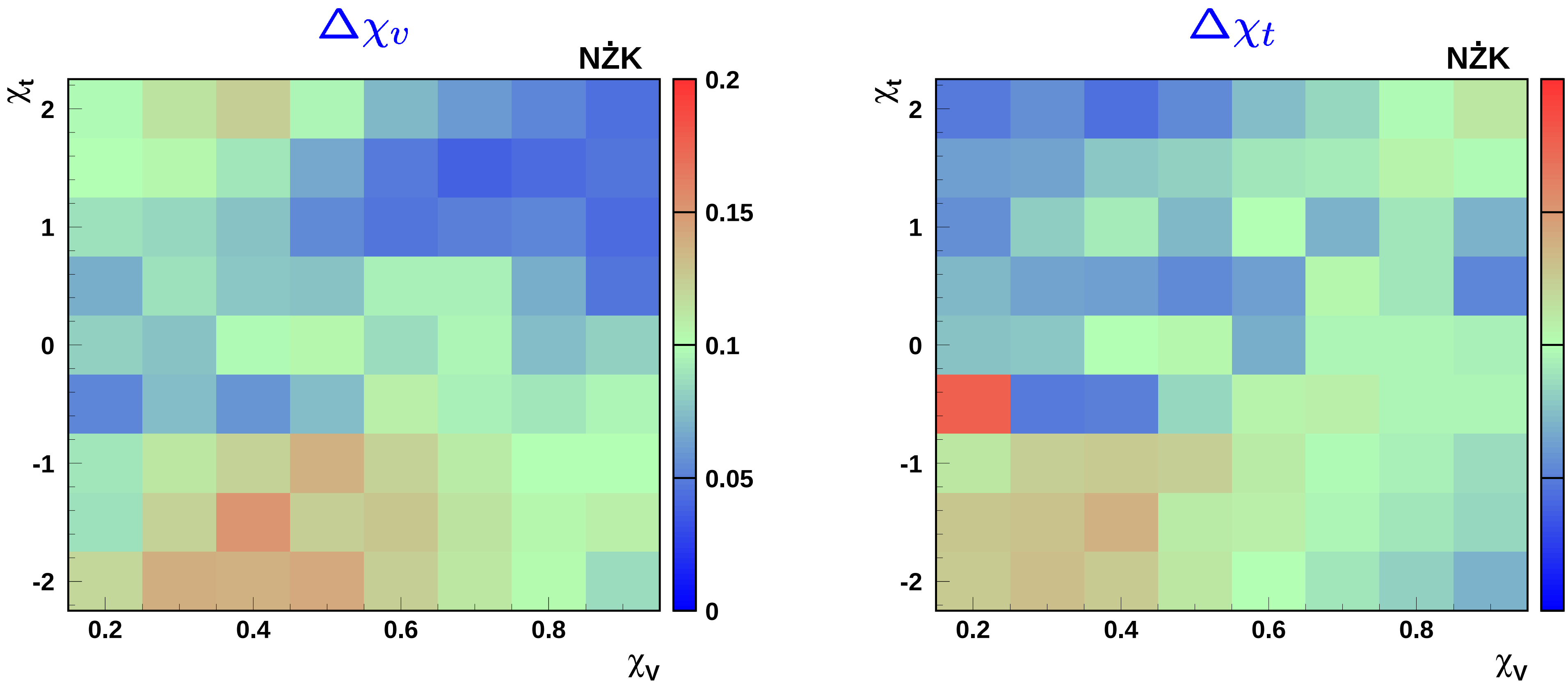
1σ contours for 1 year of PC
$M_H = 300$ GeV



General 2HDM (II)

Coupling errors

Estimated total errors on Higgs boson couplings for M_H=300 GeV (1 year of PC running)



For a wide range of couplings $\Delta\chi_v \leq 0.1$ $\Delta\chi_t \leq 0.4$

Comparison with LHC and LC

LHC

In the considered mass range 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

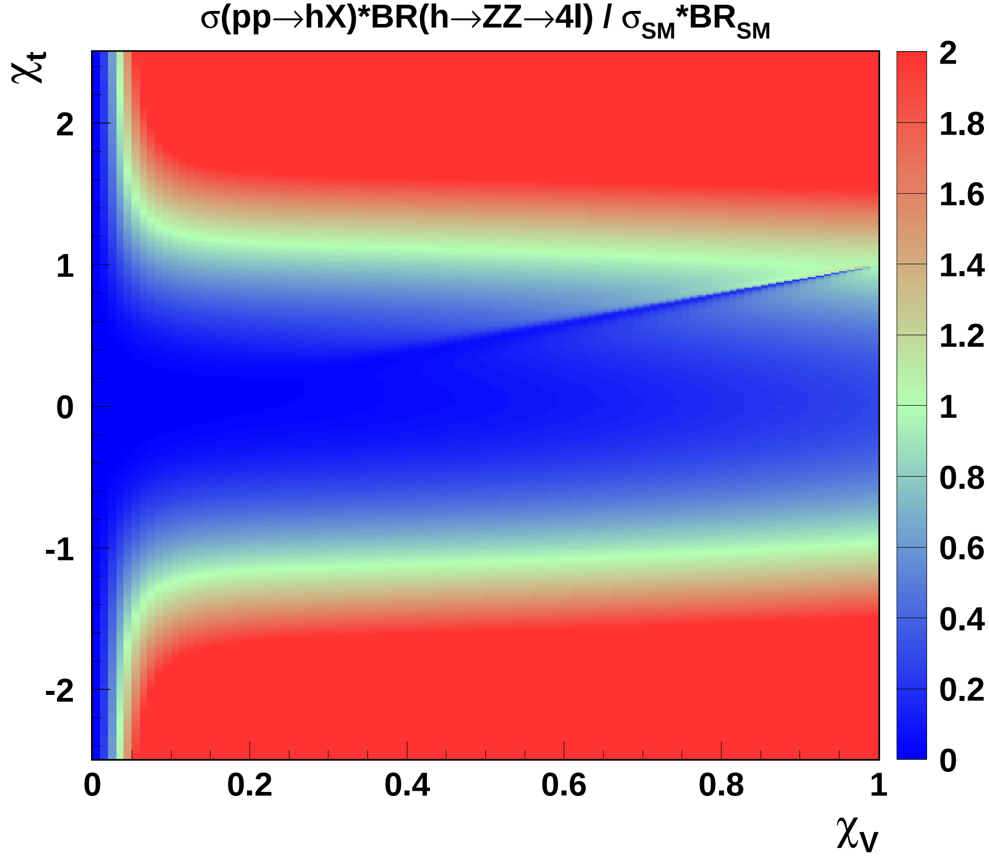
$$\sigma(pp \to hX) \cdot BR(h \to ZZ \to 4l)$$

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

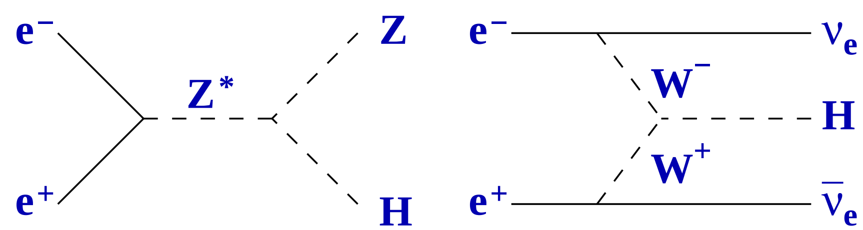


This will constrain the $|\chi_t|$ value, provided χ_V is not too small.

Comparison with LHC and LC

LC

At LC, two processes contribute to the Higgs boson production



Cross section is sensitive only to χ_V

Measurement of

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

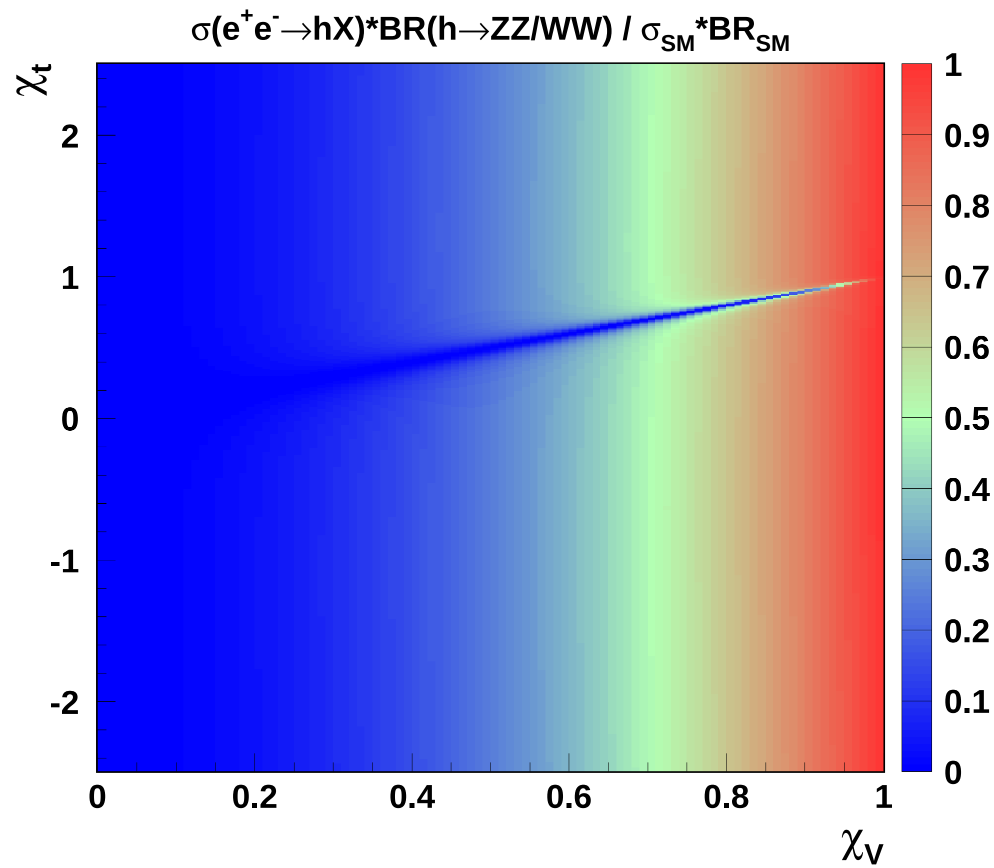
is possible with precision $\sim 4-7\%$

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



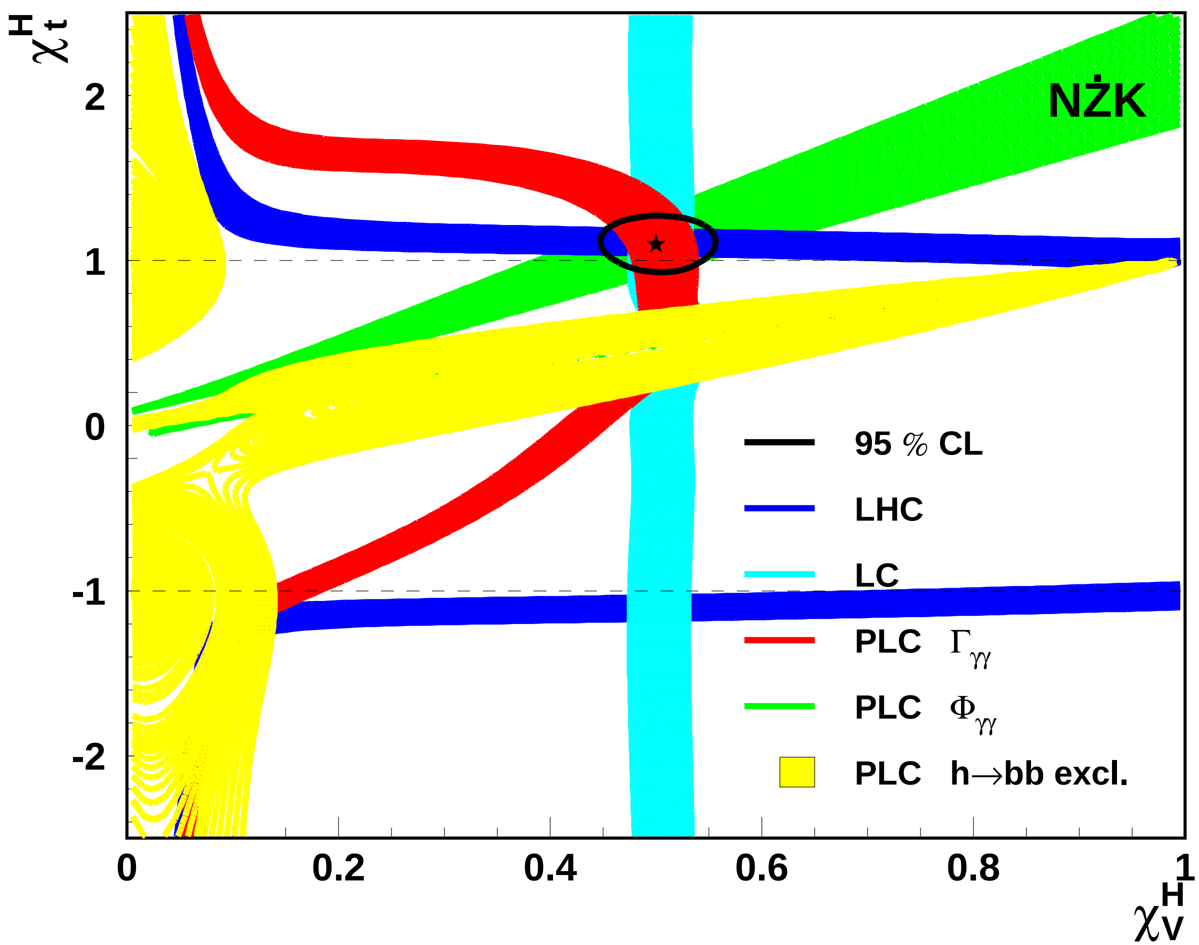
Comparison with LHC and LC

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

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

statistical errors only

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



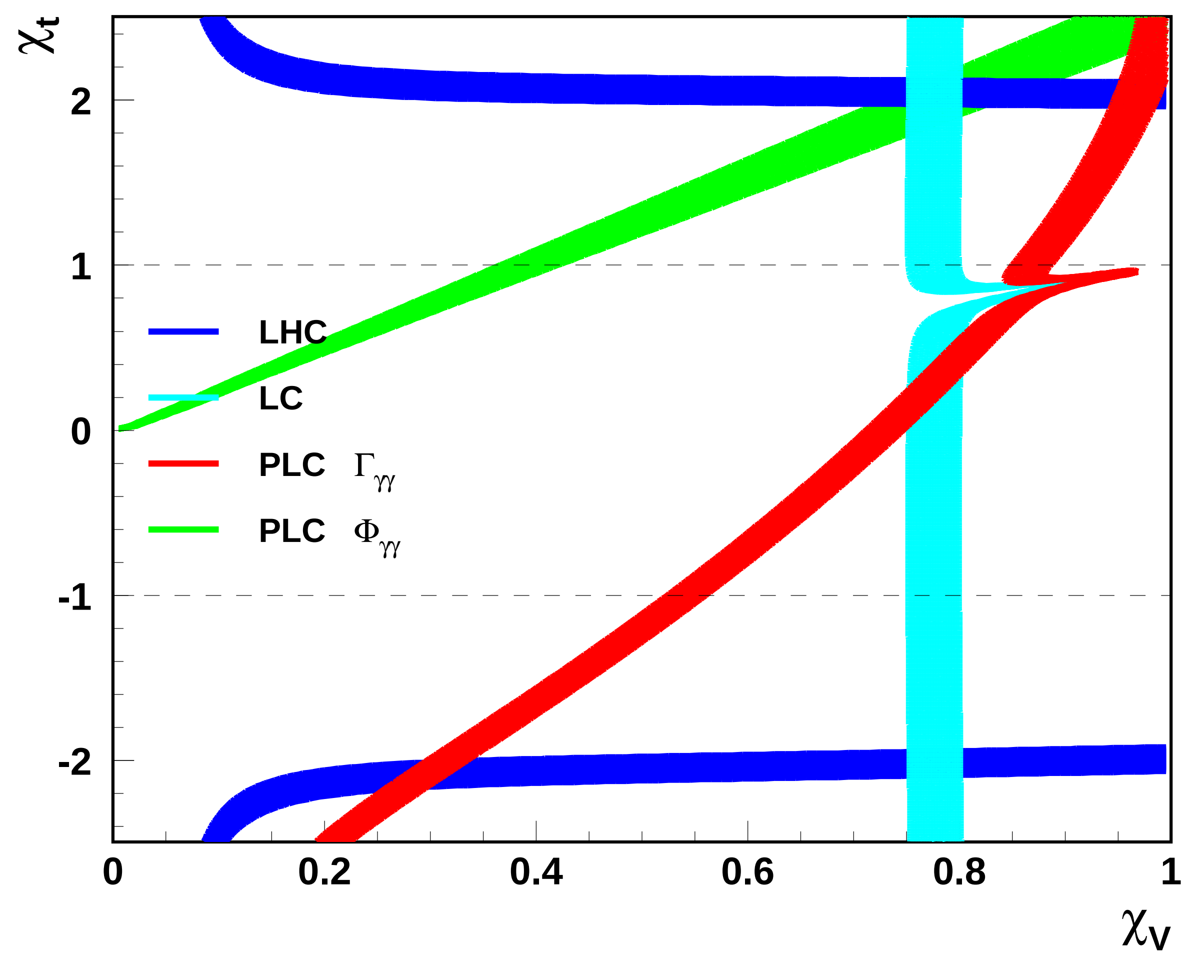
Comparison with LHC and LC

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

Inconsistency would indicate "new physics":

- different coupling structure or
- existence of new heavy particles contributing to Γ_{gg} and $\Gamma_{\gamma\gamma}$

Results for 2HDM (II) with weak CP violation:



Summary

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.

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

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

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.

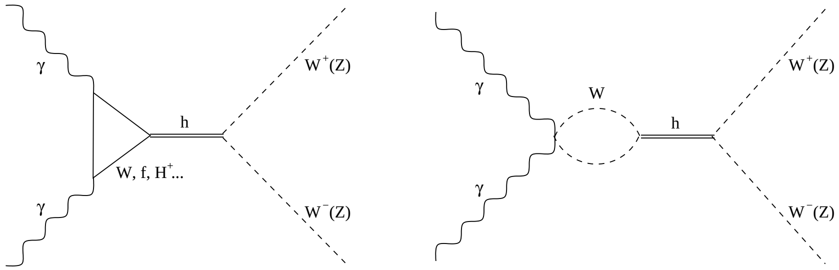
In the general 2HDM (II), Higgs boson couplings to both vector bosons (χ_v) and up fermions (χ_t) can be determined

By combining measurements from LHC, LC and PLC coupling structure and particle contents of the model can be tested.

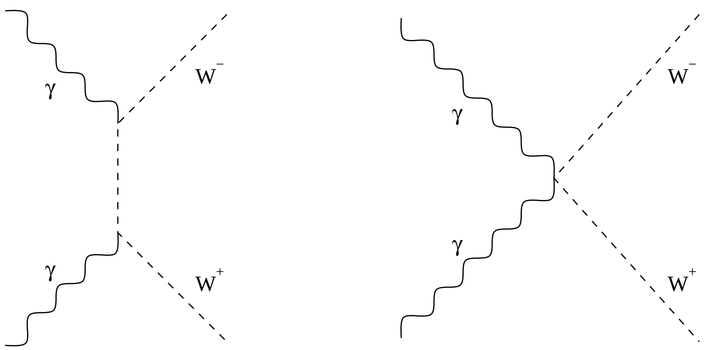
$\gamma\gamma \to \mathcal{H} \to WW,\ ZZ$

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

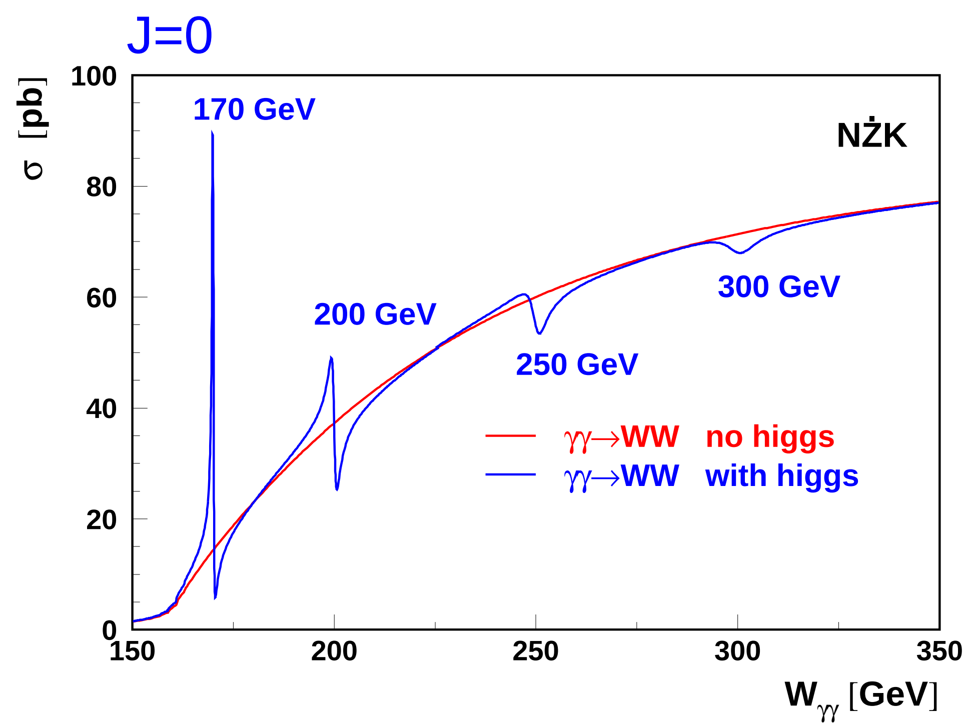
For resonant $\gamma\gamma \to h \to W^+W^-$ signal



there is a large non-resonant bg.



Large interference effects are expected in the considered mass range



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

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

Simulation

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

$\gamma\gamma \to W^+W^-,\ ZZ$ 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

2HDM(II)

Systematic uncertainties

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

Uncertainties:	Parameters:
• luminosity	⇒ overall normalization relative normalization of WW and ZZ samples fixed
• energy scale • Higgs boson mass	⇒ Higgs boson mass
• mass resolution • Higgs boson width	⇒ Higgs boson width
• luminosity spectra	⇒ spectra shape variations:

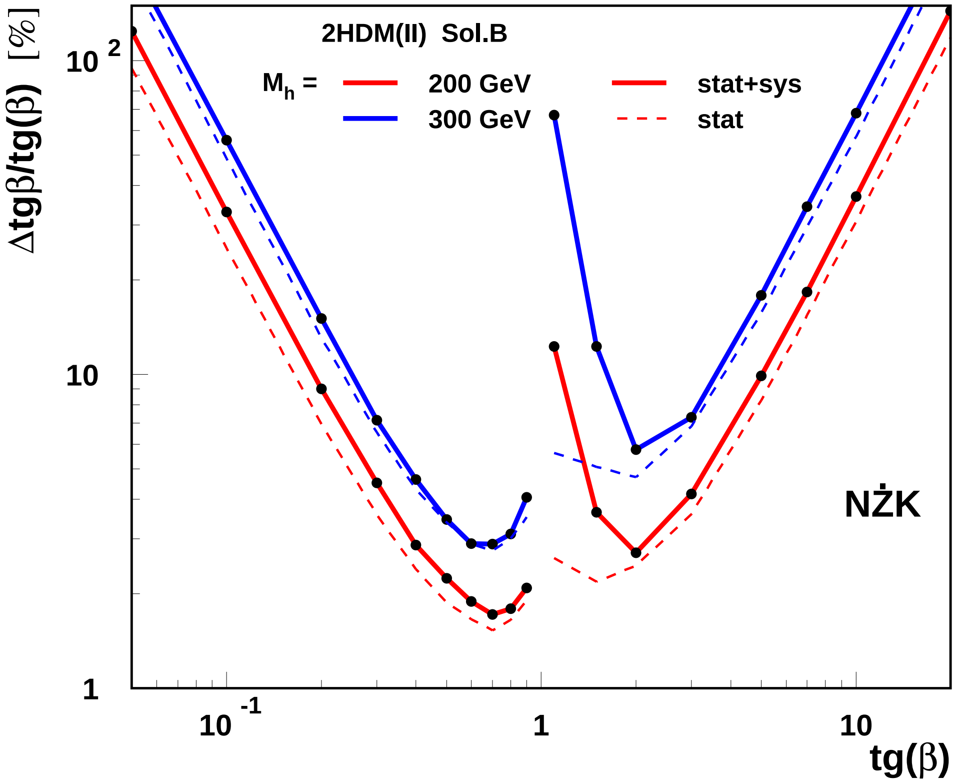
$$\frac{dL}{dW_{\gamma\gamma}} = \frac{dL^{CompAZ}}{dW_{\gamma\gamma}}(1 + A \cdot \sin \pi x + B \cdot \sin 2\pi x) \qquad x = \frac{W_{\gamma\gamma} - W_{min}}{W_{max} - W_{min}}$$

SM-like 2HDM(II)

Light Higgs boson h

Influence of systematic uncertainties

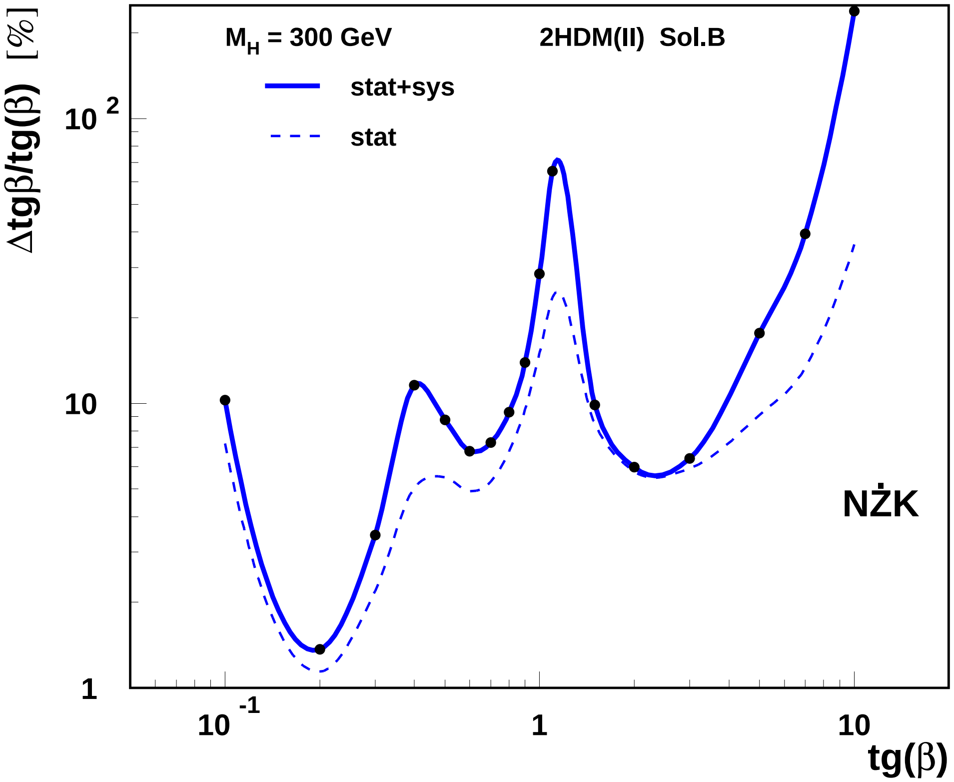
for $M_h = 200$ GeV and $M_h = 300$ GeV



Heavy Higgs boson H

Influence of systematic uncertainties

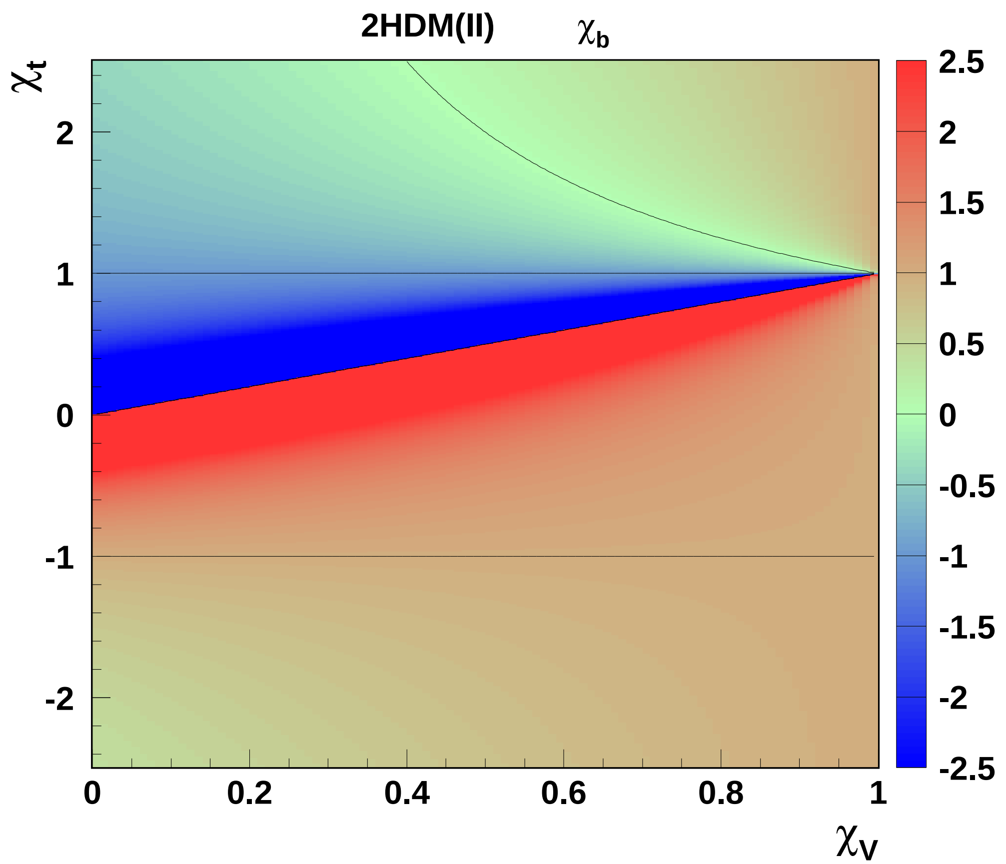
for $M_H = 300$ GeV



General 2HDM (II)

Basic relative coupling to down-type fermions as a function of vector boson and top (up-type fermions) couplings:

$$\chi_d = \chi_V + \frac{1 - \chi_V^2}{\chi_V - \chi_u}$$

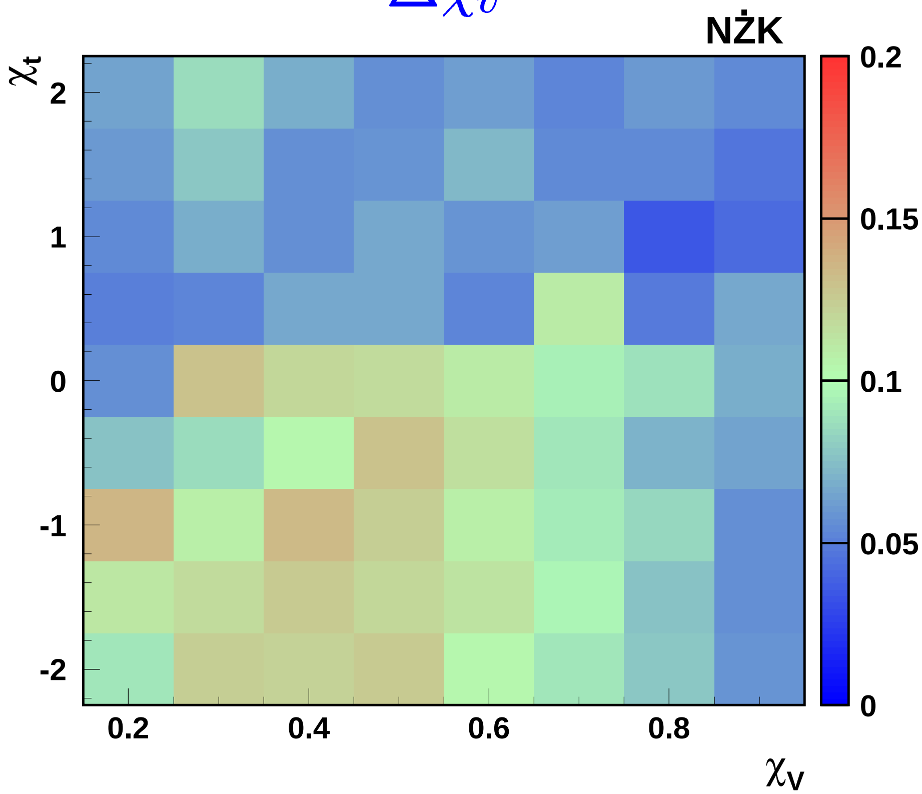


General 2HDM (II)

Coupling errors

Estimated total errors on Higgs boson couplings for M_H=200 GeV (1 year of PC running)

$\Delta\chi_v$



$\Delta\chi_t$