Determination of the basic Higgs-boson couplings from combined analysis of WW/ZZ decays at LHC, LC and Photon Collider

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NŻK

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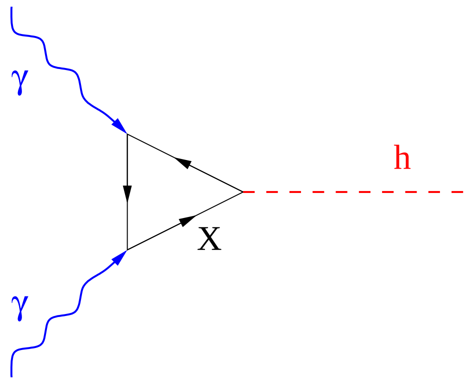
Outline:

- Introduction: Higgs boson production and decays to WW and ZZ at PC
  JHEP 0211 (2002) 034 [hep-ph/0207294]
- CP conserving 2HDM(II)
  $\Rightarrow$ Photon Collider results
  $\Rightarrow$ comparison with LHC and LC
- 2HDM(II) with CP violation
  $\Rightarrow$ Combined analysis: LHC, LC & PC

Introduction

Higgs boson production at the Photon Collider

Cross section proportional to the two-photon width



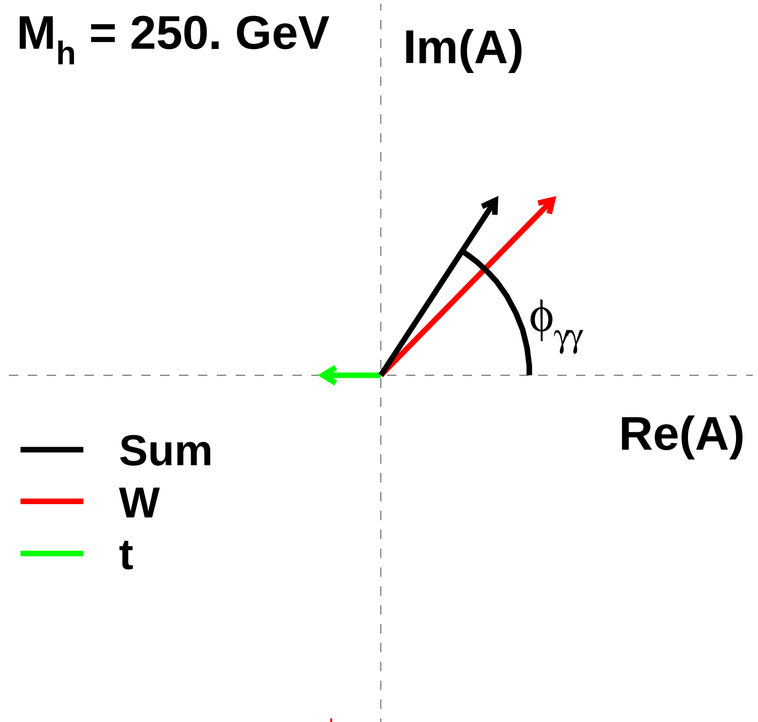
$$\Gamma(h \rightarrow \gamma\gamma) = \frac{G_F \alpha^2 M_h^3}{128\sqrt{2}\,\pi^3} \cdot |\mathcal{A}|^2$$

two-photon amplitude:

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

$$\mathcal{A} = |\mathcal{A}|\, e^{\,i\,\phi_{\gamma\gamma}}$$

In SM, dominant contributions to $\mathcal{A}$ from $W^\pm$ and top loops



Different phases of $W^\pm$ and top contributions

$\Rightarrow$ both $\Gamma_{\gamma\gamma}$ and $\phi_{\gamma\gamma}$ depend on Higgs couplings!

Introduction

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 described by convolution of:

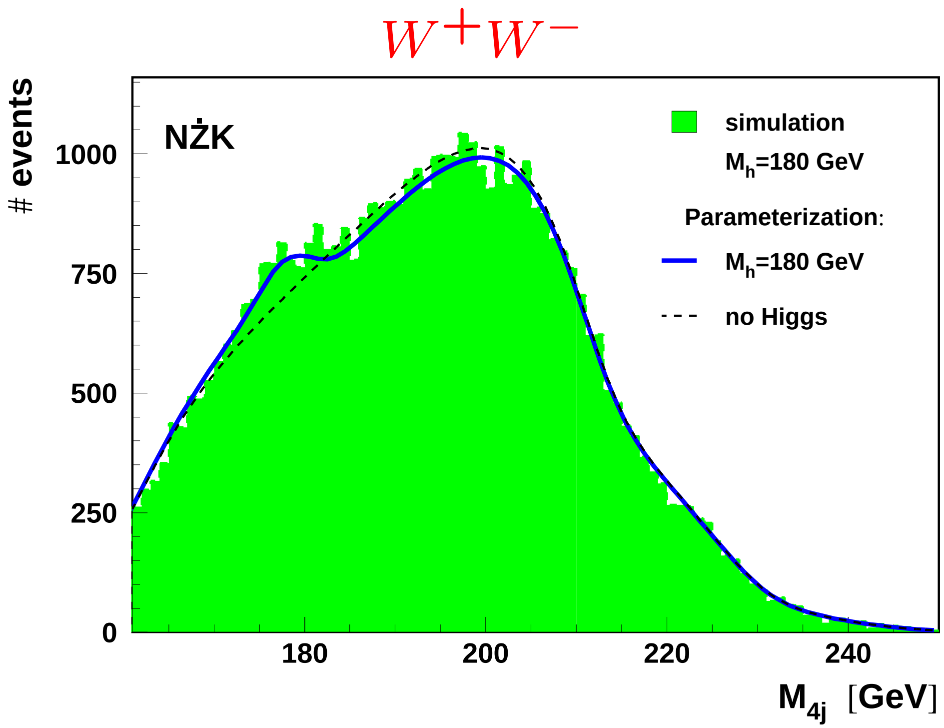
- analytical luminosity Spectra **CompAZ**
- cross section formula
  for signal + background + interf.
- invariant mass resolution
  parametrized as a function of $W_{\gamma\gamma}$

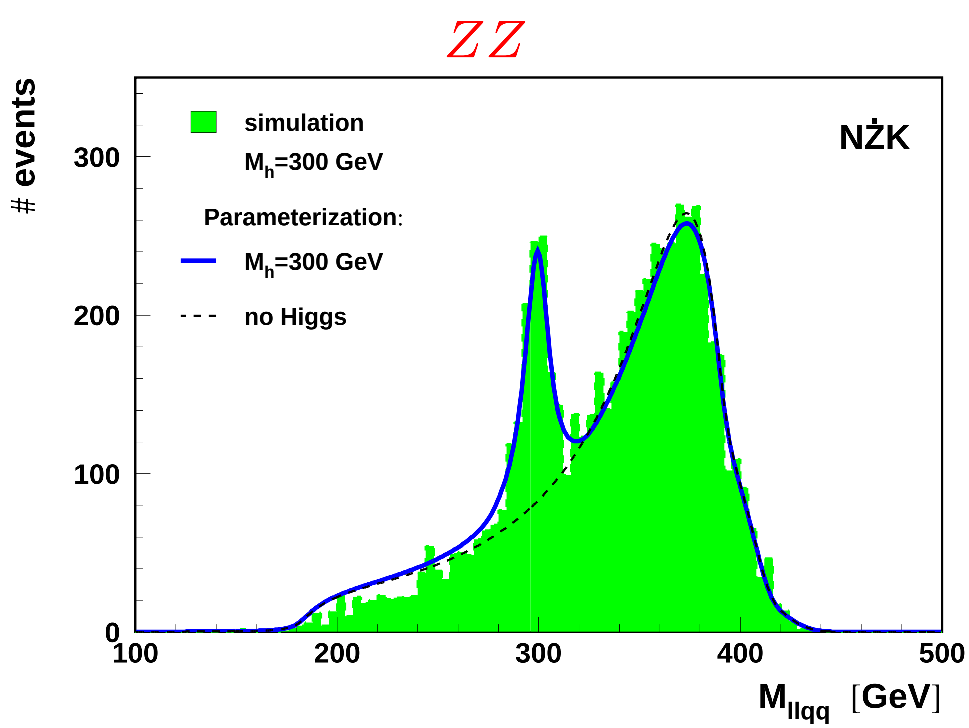
$\Rightarrow$ mass spectra can be calculated for any $\sqrt{s_{ee}}$ and M_h without time-consuming MC simulation

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

Introduction

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 (stat.+sys.)

JHEP 0211 (2002) 034 [hep-ph/0207294] (stat. uncertainties only)

ECFA/DESY workshop, Praha 2002 (stat. and sys. uncertainties)

CP conserving 2HDM (II)

Higgs boson couplings

Scalar Higgs bosons h and H
with 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"

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

I. F. Ginzburg, M. Krawczyk and P. Osland,
hep-ph/0101331

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

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

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

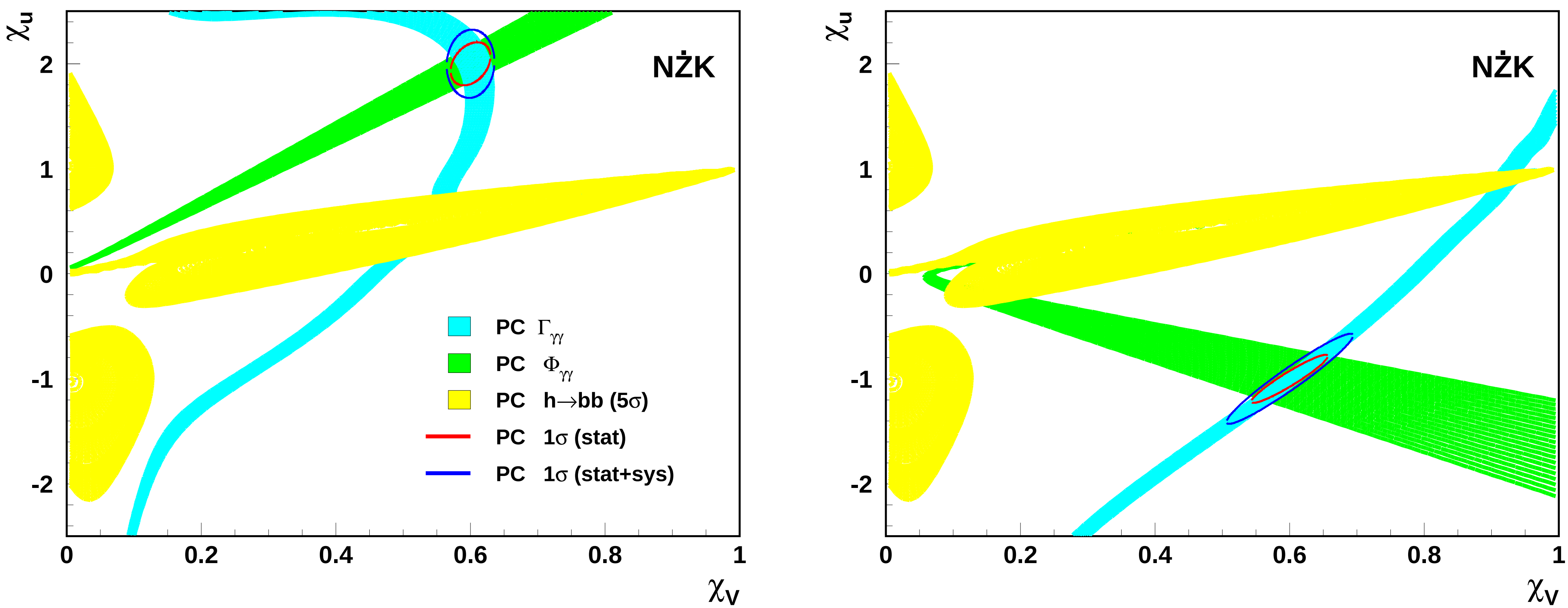
Photon Collider

Combined fit to W^+W^- and ZZ invariant mass distributions $\Rightarrow$ $\Gamma_{\gamma\gamma}$ and $\phi_{\gamma\gamma}$

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

1σ contours for 1 year of PC running, $M_H = 250$ GeV

$\chi_V = 0.7$ $\chi_u = 1.5$ $\chi_V = 0.7$ $\chi_u = -1$



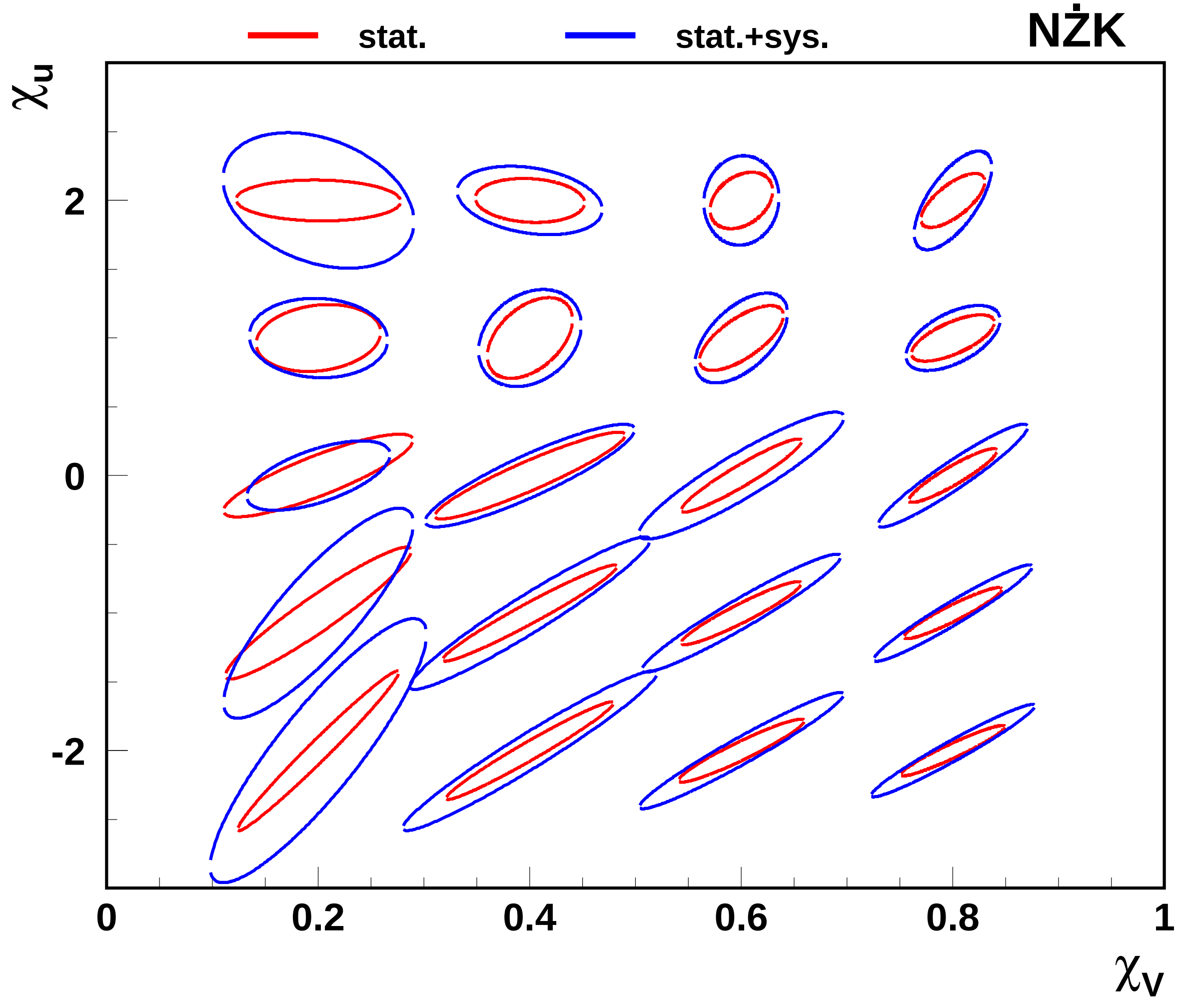
Systematic uncertainties affect mainly $\phi_{\gamma\gamma}$ measurement !

Photon Collider

Comparison of statistical and total (stat+sys) error estimates, for $M_H = 250$ GeV

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

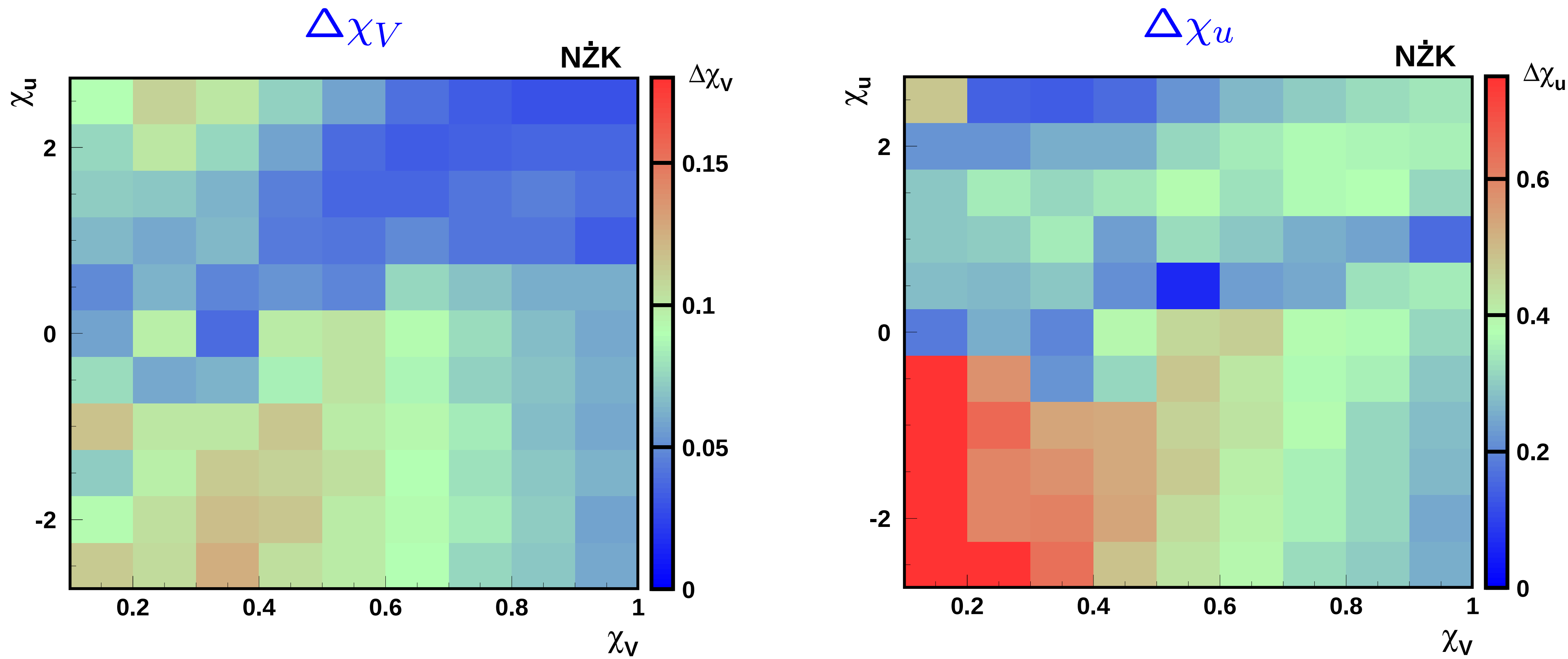
1σ contours for 1 year of PC



Photon Collider

Coupling uncertainties

Estimated total errors on Higgs boson couplings for M_H=250 GeV (1 year of PC running)



For a wide range of couplings $\Delta\chi_V \leq 0.1$ $\Delta\chi_u \leq 0.4$

For M_H = 200 $\rightarrow$ 300 GeV: $\langle\Delta\chi_V\rangle$ = 0.082 $\rightarrow$ 0.090 $\langle\Delta\chi_u\rangle$ = 0.49 $\rightarrow$ 0.36

LHC

In the considered mass range Higgs production at LHC is dominated by the gluon fusion process (top loop)

$$\sigma(gg \to h) \;\sim\; \chi_u^2$$

WW fusion process ($\sim$ 15%)

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

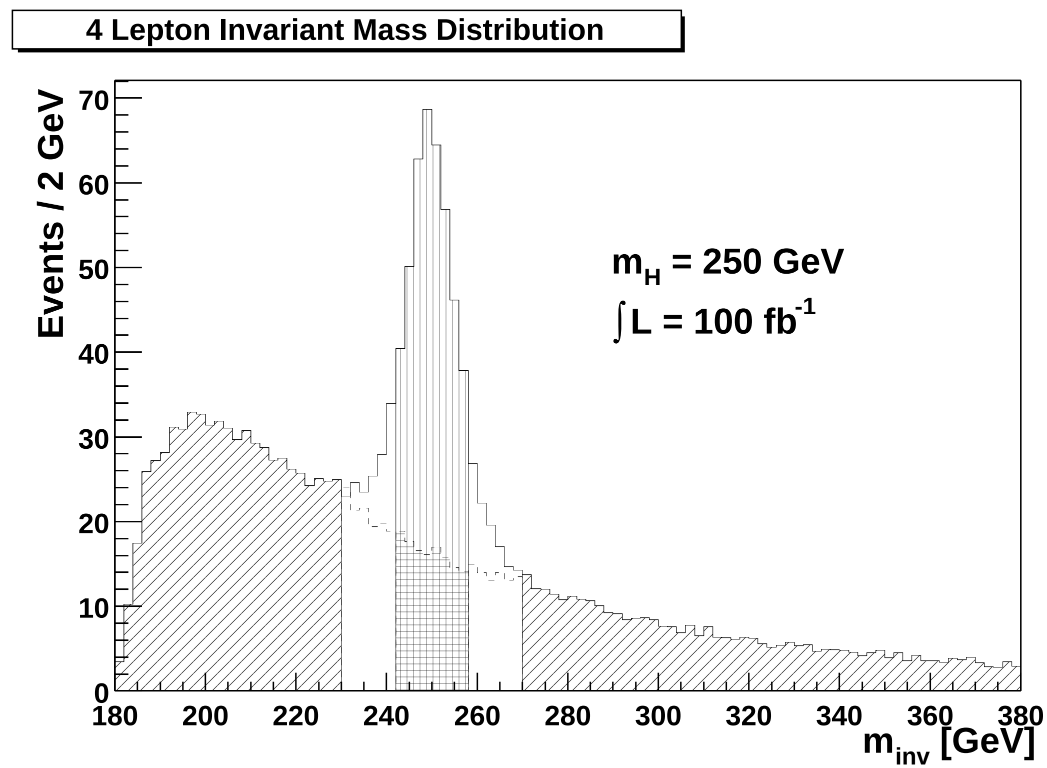
Measurement of

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

is possible with precision $\sim$ 15%

We use results of

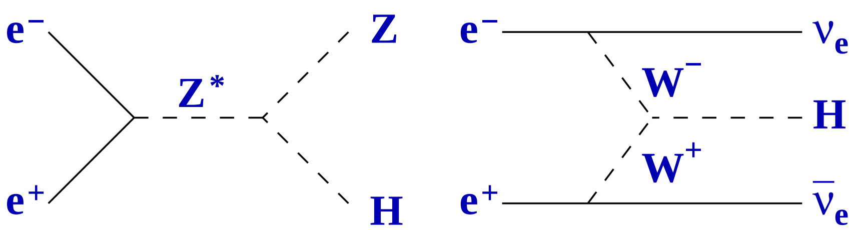
C.P.Buszello, I.Fleck, P.Marquard, J.J. van der Bij, Eur. Phys. J. C32 (2004) 209 hep-ph/0212396



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

LC

At LC, two processes contribute to the Higgs boson production



Cross section is sensitive only to χ_V

Measurement of

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

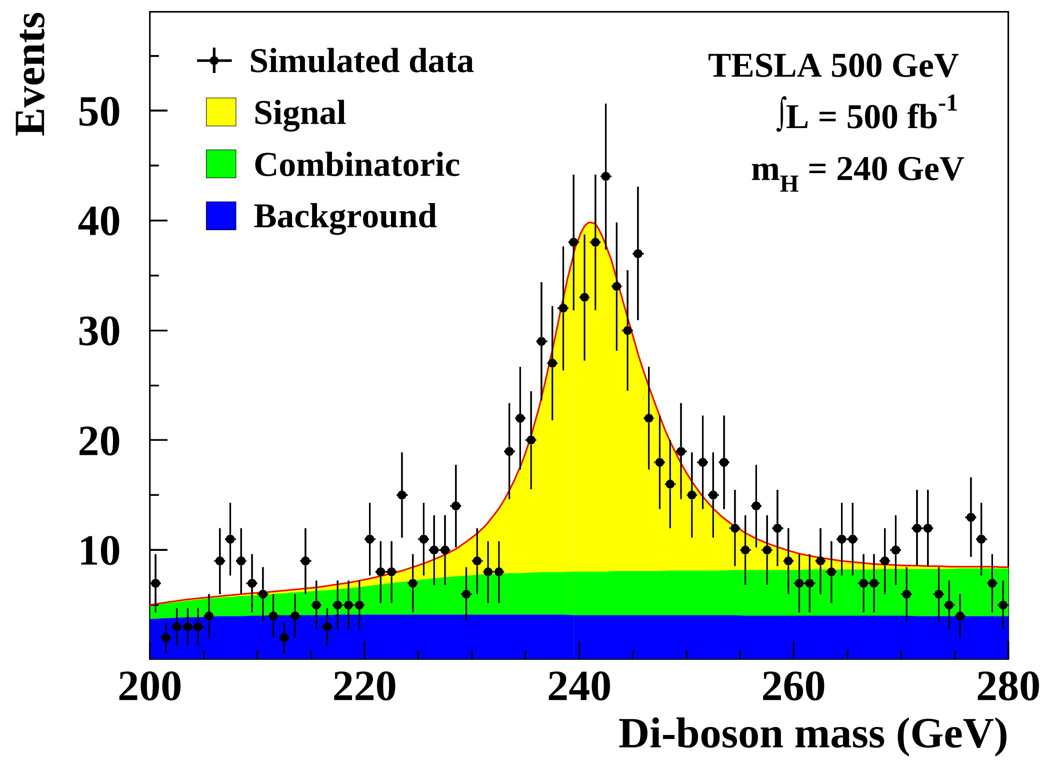
is possible with precision $\sim 4 - 7\%$

This will constrain the χ_V value

We thank Niels Meyer for providing us the data

N.Meyer, Eur. Phys. J. C35 (2004) 171

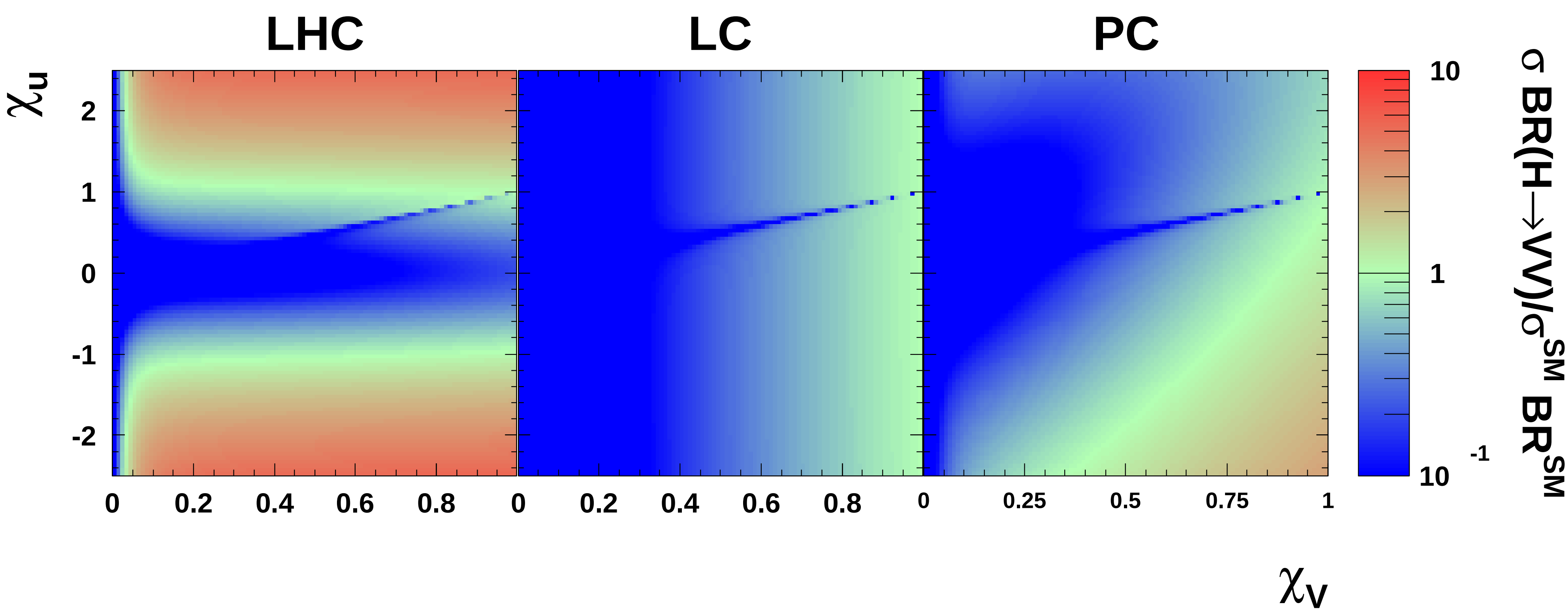
hep-ph/0308142



LHC $\oplus$ LC $\oplus$ PC

Measurements at LHC, LC and Photon Collider are complementary, being sensitive to different combinations of Higgs-boson couplings

Cross sections $\times$ BR relative to SM $\qquad M_H = 250 GeV$



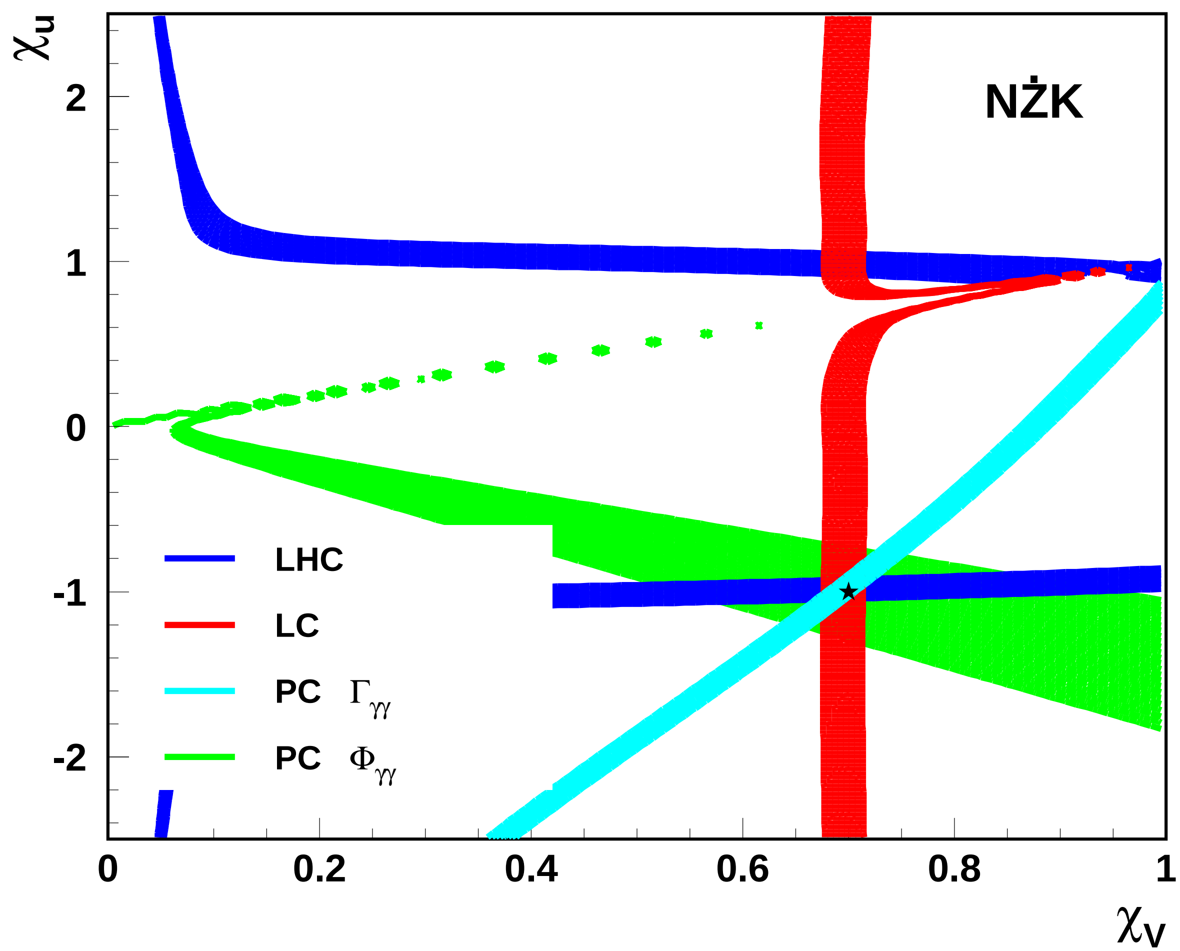
LHC $\oplus$ LC $\oplus$ PC

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

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

statistical errors only

$\chi_V = 0.7 \qquad \chi_u = -1 \qquad M_H = 250$ GeV



2HDM (II) with CP violation

$H - A$ mixing

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

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

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

$\Rightarrow$ additional model parameter: **CP-violating mixing phase Φ_{HA}**

$\Rightarrow$ see our paper hep-ph/0403138

In general case

combined analysis of LHC, Linear Collider and Photon Collider data is needed

Results for h_2 production and decays...

LHC $\oplus$ LC $\oplus$ PC

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

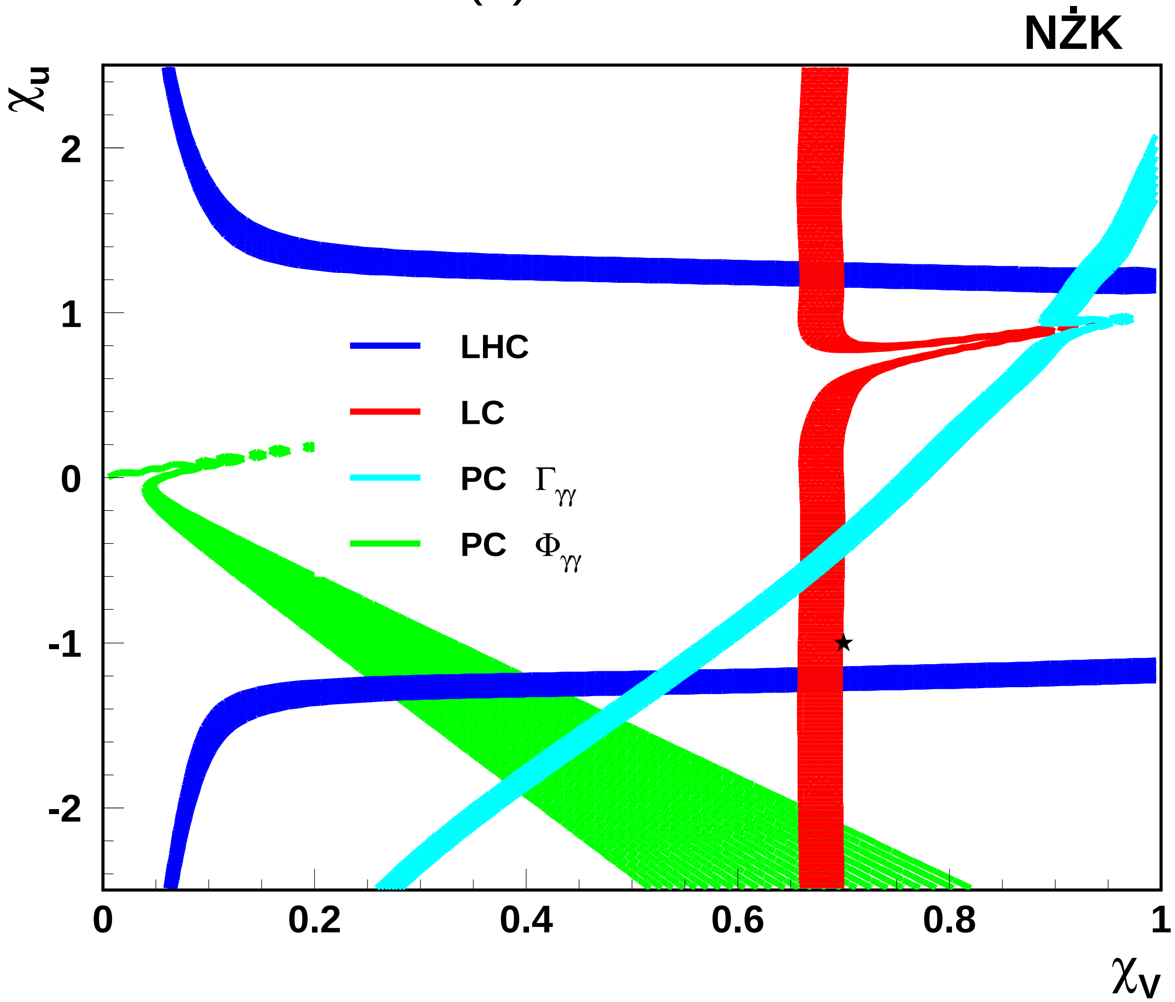
Inconsistency would indicate "new physics":

- different coupling structure

  or

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

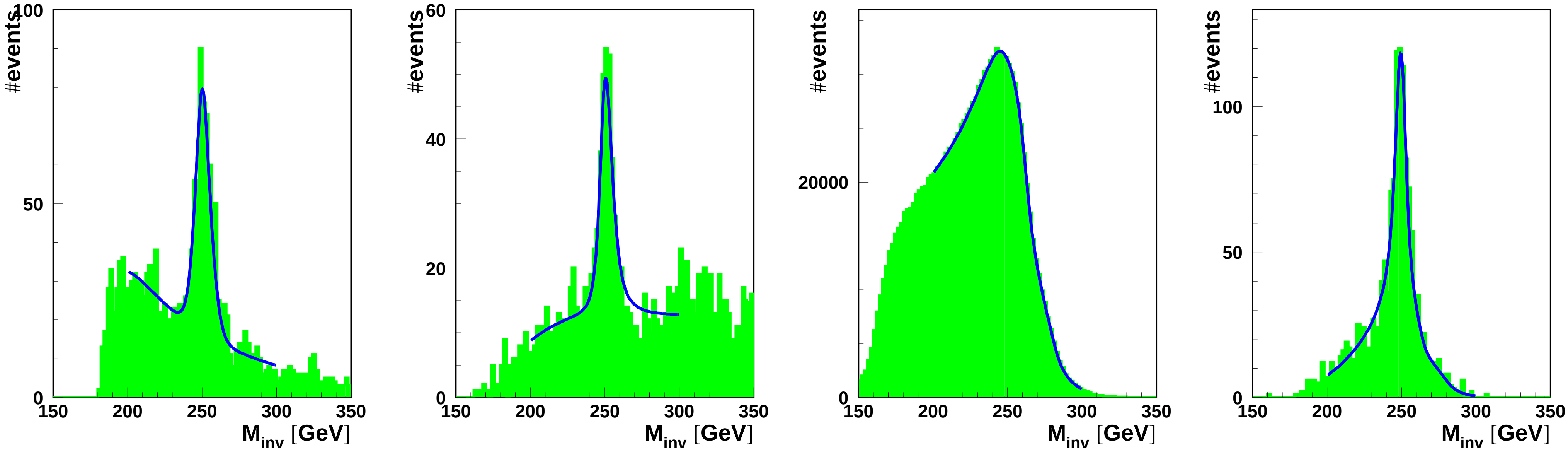
Results for 2HDM (II) with weak CP violation:



LHC $\oplus$ LC $\oplus$ PC

Combined fit to the expected invariant mass distributions:

LHC | LC | PC $H \to WW$ | PC $H \to ZZ$



9 or 10 parameter fit: • χ_V • χ_u • M_H • Φ_{HA} (for model with CP violation)

$+$ 6 normalization and $\gamma\gamma$-spectra shape parameters (systematic uncertainties)

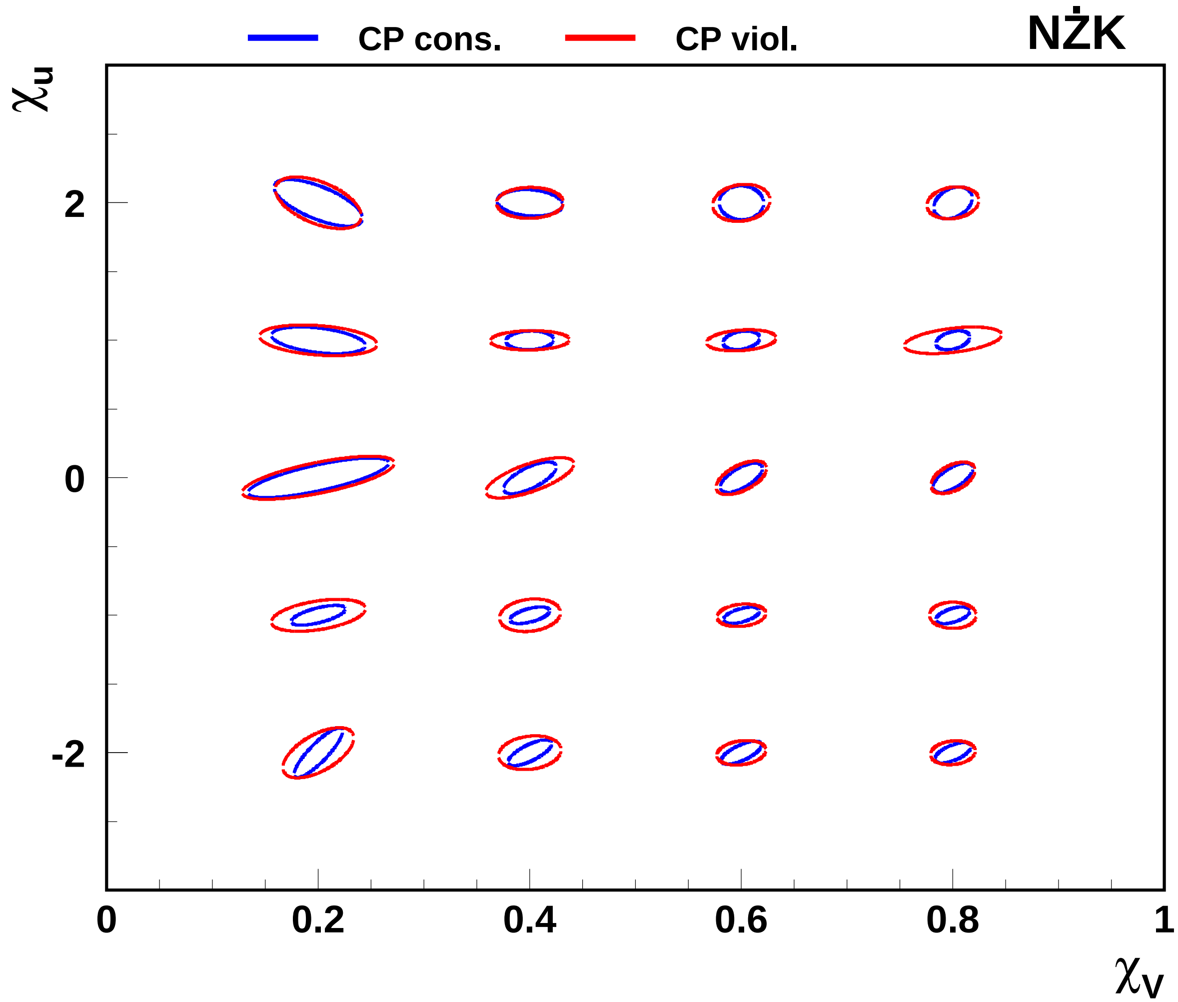
LHC $\oplus$ LC $\oplus$ PC

Simultaneous fit to LHC, LC and PC (W^+W^- and ZZ) invariant mass distributions

1σ (stat.+sys.) contours

Comparison of error contours for model without and with weak CP violation

H couplings to vector bosons (χ_V) and up fermions (χ_u) for $M_H = 250$ GeV



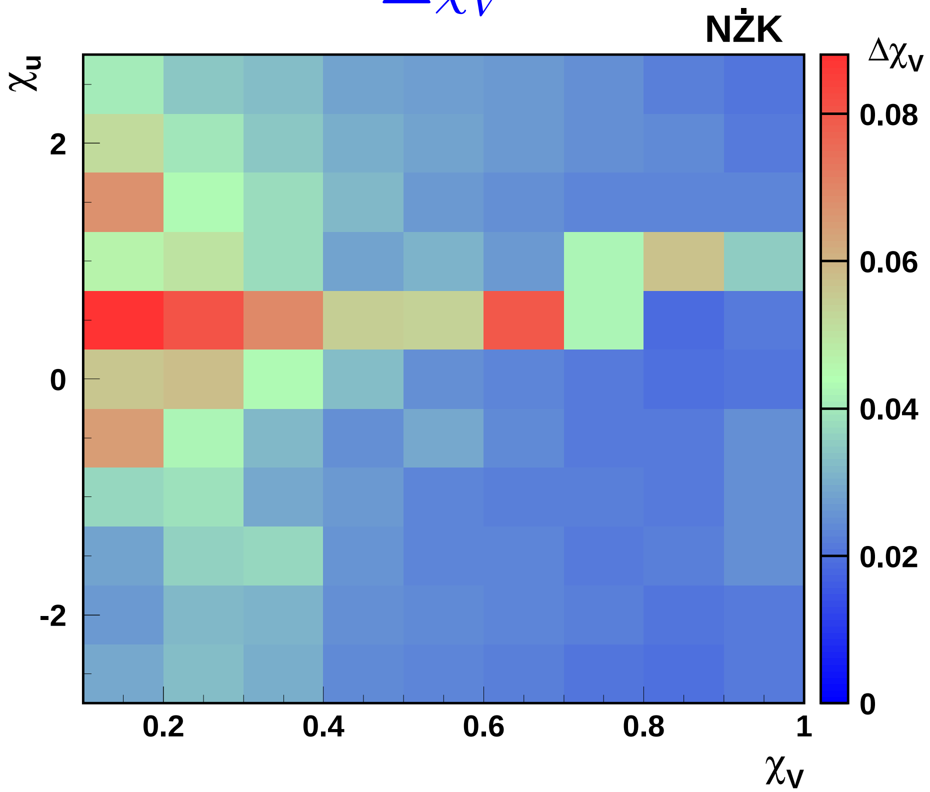
coupling errors $\Rightarrow$ next slide

LHC $\oplus$ LC $\oplus$ PC

Coupling errors

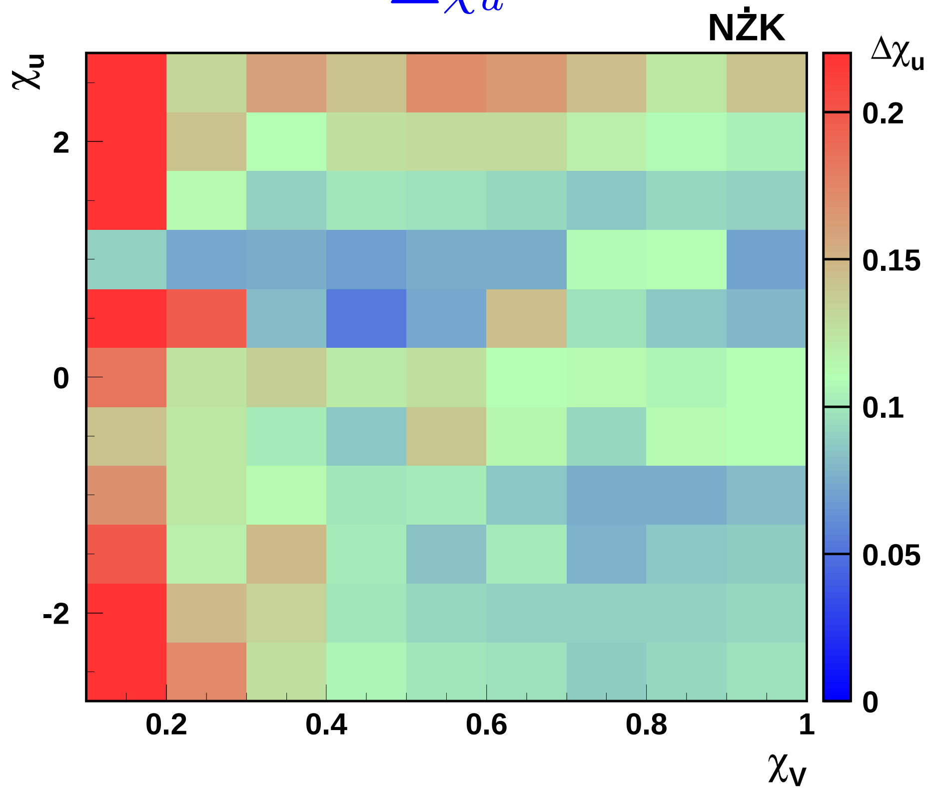
Estimated total errors on Higgs boson couplings for M_H=250 GeV

$\Delta\chi_V$



$\langle\Delta\chi_V\rangle$ = 0.033

$\Delta\chi_u$



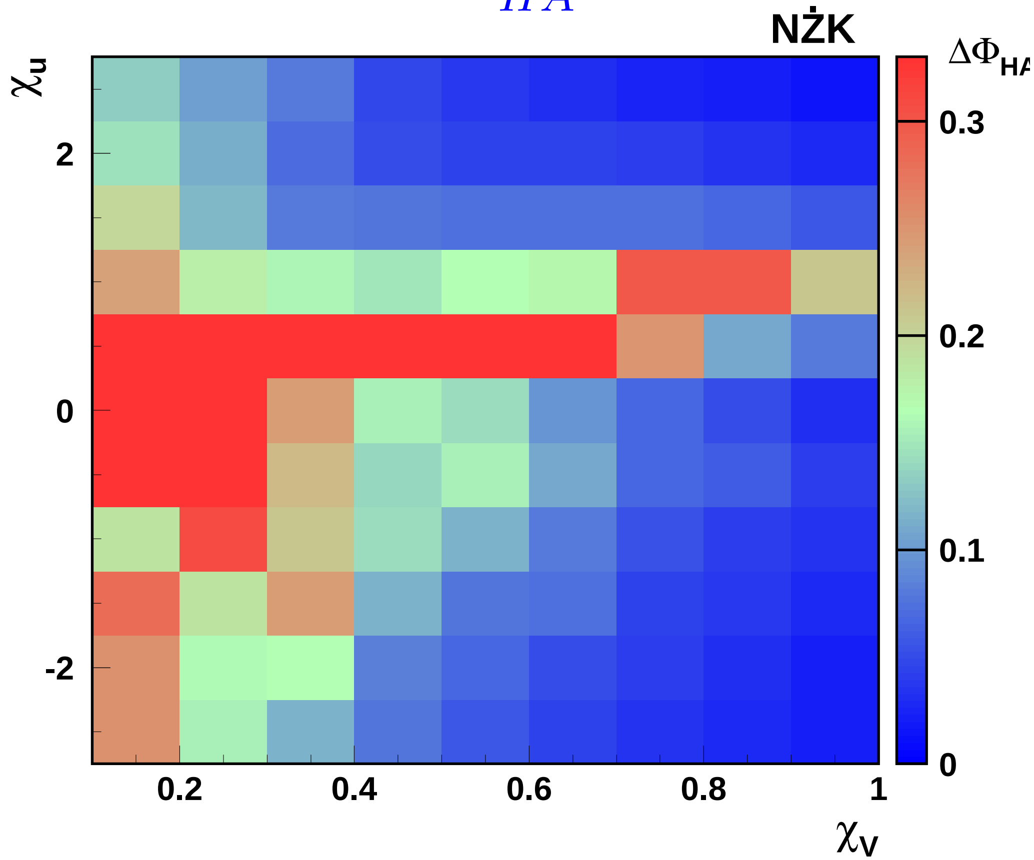
$\langle\Delta\chi_u\rangle$ = 0.12

LHC $\oplus$ LC $\oplus$ PC

Φ_{HA} error

Estimated total errors on $H-A$ mixing angle, for M_H=250 GeV

$\Delta\Phi_{HA}$



For a wide range of couplings

$\Delta\Phi_{HA} \leq 100$ mrad

$\langle\Delta\Phi_{HA}\rangle$ = 150 mrad

Summary

CP-conserving 2HDM(II)

Higgs-boson couplings to vector bosons, χ_V, and to up-type fermions, χ_u, can be determined at the Photon Collider with $\Delta\chi_V \sim 0.1$ and $\Delta\chi_u \sim 0.4$

Measurements at Photon Collider complementary to those at LHC and LC, being sensitive to different combinations of Higgs-boson couplings.

2HDM (II) with CP violation

Only the combined analysis of LHC, LC and PC measurements allows for the determination of the CP-violating $H - A$ mixing angle Φ_{HA}.

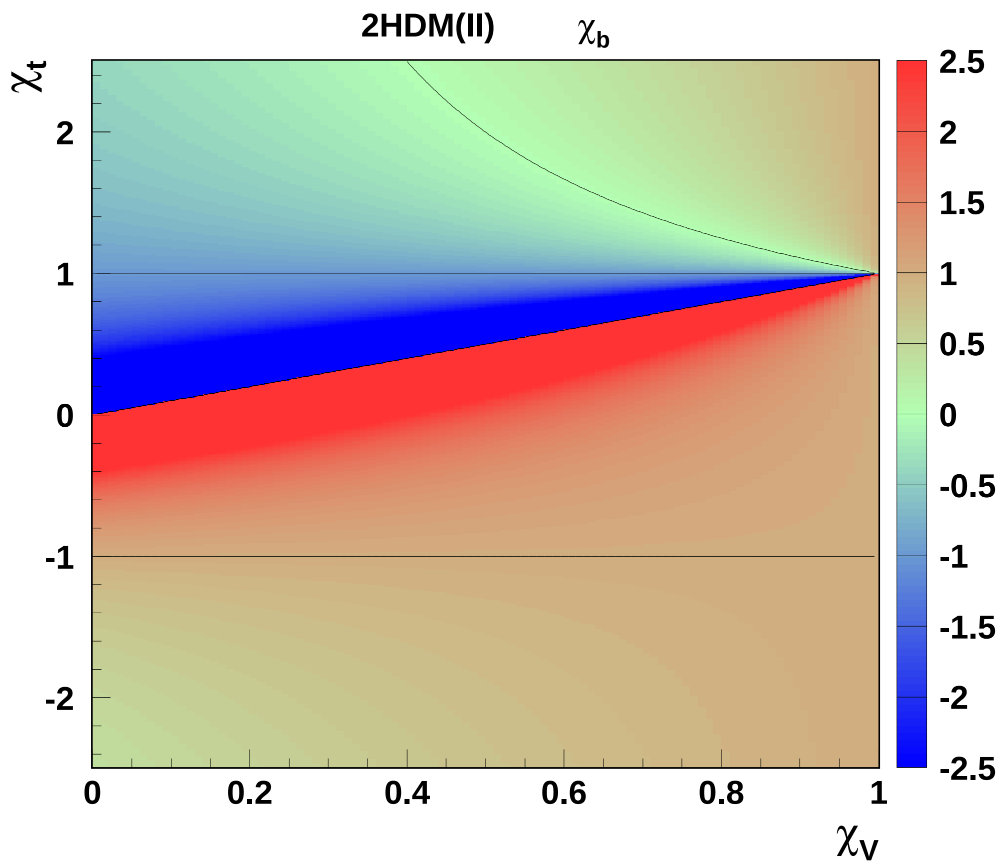
In most of the considered parameter space Φ_{HA} measured to better than 100 mrad.

Results submitted to ICHEP'04 (abstract 12-0740) and as an LC-Note

2HDM (II)

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

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



Systematic uncertainties

PC analysis

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

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

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

Systematic uncertainties

LHC $\oplus$ LC $\oplus$ PC analysis

Parameter:	Assumed uncertainty:
• Higgs boson mass	$\Rightarrow$ unconstrained
• $\gamma\gamma$ luminosity	$\Rightarrow$ unconstrained
• $\gamma\gamma$ spectra shape parameters	$\Rightarrow$ 5% uncertainty
• background normalization for e^+e^-	$\Rightarrow$ 5% uncertainty
• signal normalization for pp	$\Rightarrow$ 10% uncertainty
• background normalization for pp	$\Rightarrow$ 10% uncertainty