

Simulation of the Higgs boson production at LHC, ILC and PLC

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NŻK

PLC2005
Kazimierz, September 6, 2005

Outline

- Higgs couplings in 2HDM (II)
- Production of H at LHC, ILC, and PLC
- Combined fit of H couplings

- Coupling constraints from h production measurements

CP conserving 2HDM (II)

Higgs boson couplings

Scalar Higgs bosons h and H
with basic couplings (relative to SM):

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

	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

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

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

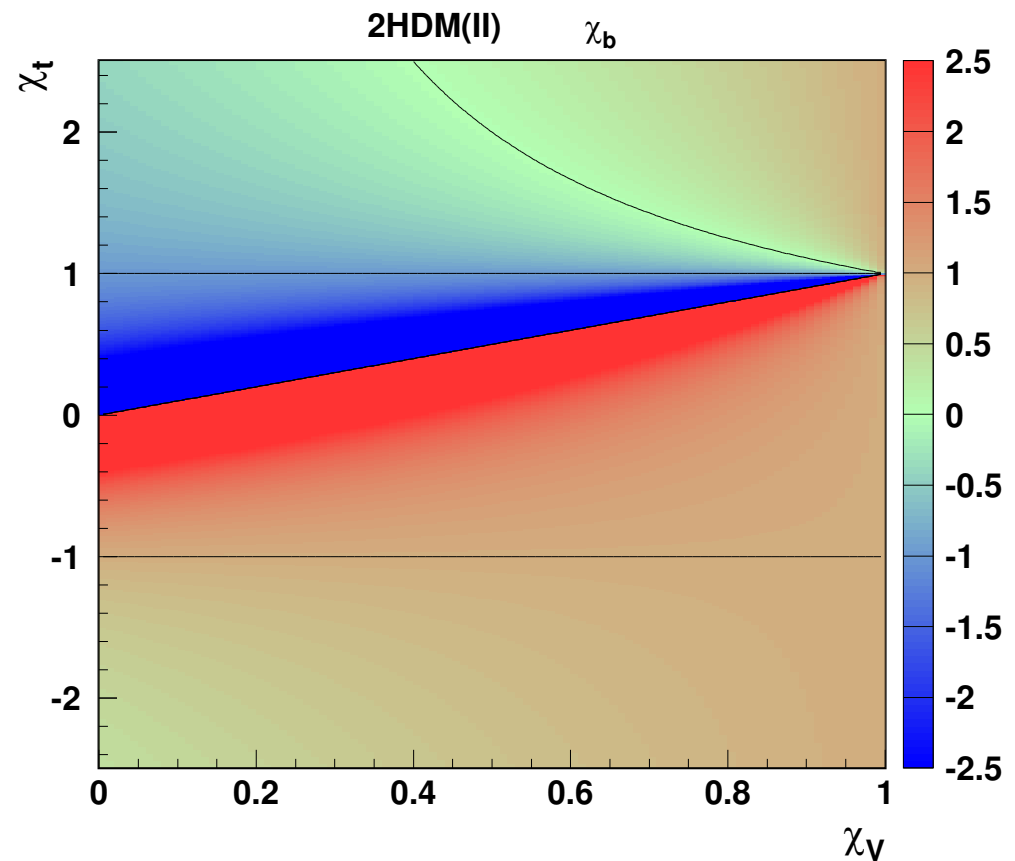
$$0 \leq \chi_V \leq 1$$

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

2HDM (II)

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

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



2HDM (II)

Heavy scalar Higgs boson

Production at LHC, ILC and PLC, for Higgs boson mass between 200 and 350 GeV

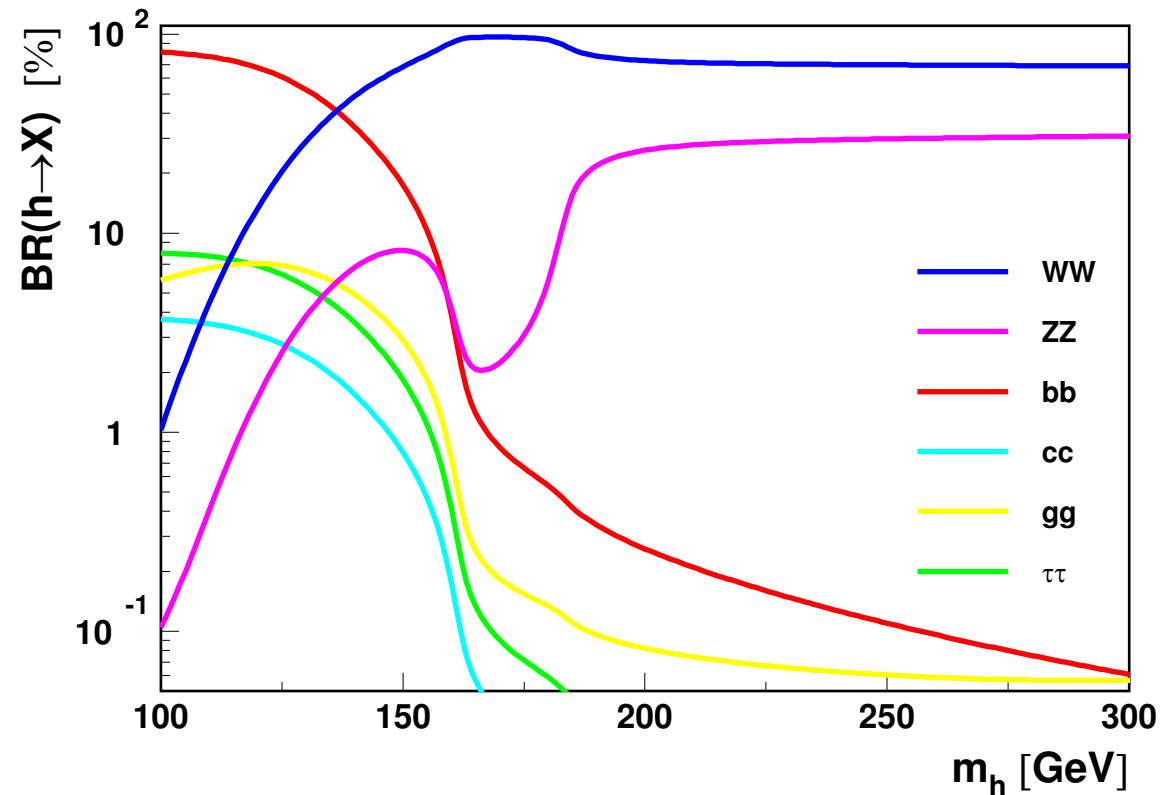
For **SM-like scenarios** ($\chi \sim 1$) Higgs boson decays to WW and ZZ dominate.

Light scalar Higgs boson

Production at LHC, ILC and PLC, for Higgs boson mass of 120 GeV

Higgs boson decays to $b\bar{b}$ considered.

SM branching ratios



LHC

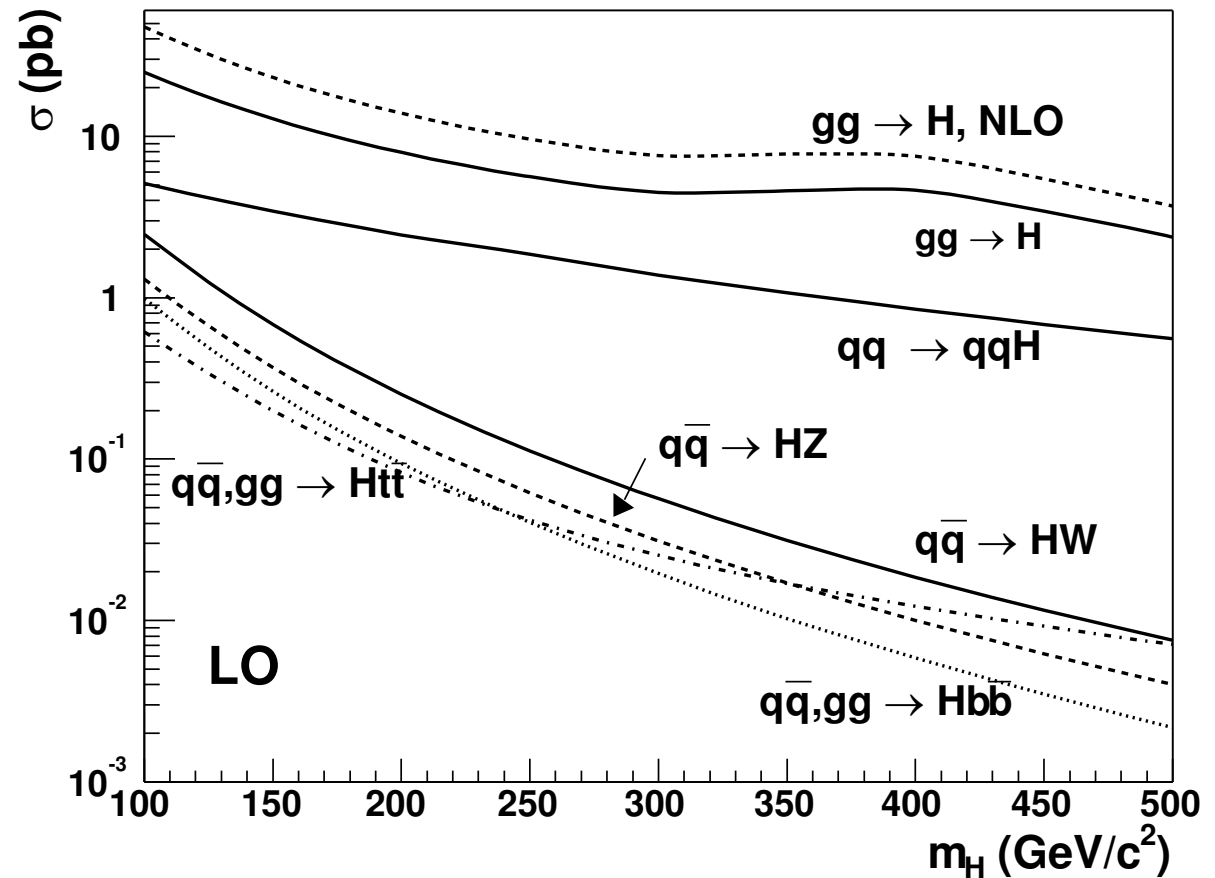
In the considered mass range Higgs boson production at LHC is dominated by the **gluon fusion** process.

Γ_{hgg} is dominated by the **top loop** contribution \Rightarrow

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

WW fusion process contributes to about 15% of cross section

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



SM Higgs boson production at LHC

LHC

Measurement of the production cross section times branching ratio

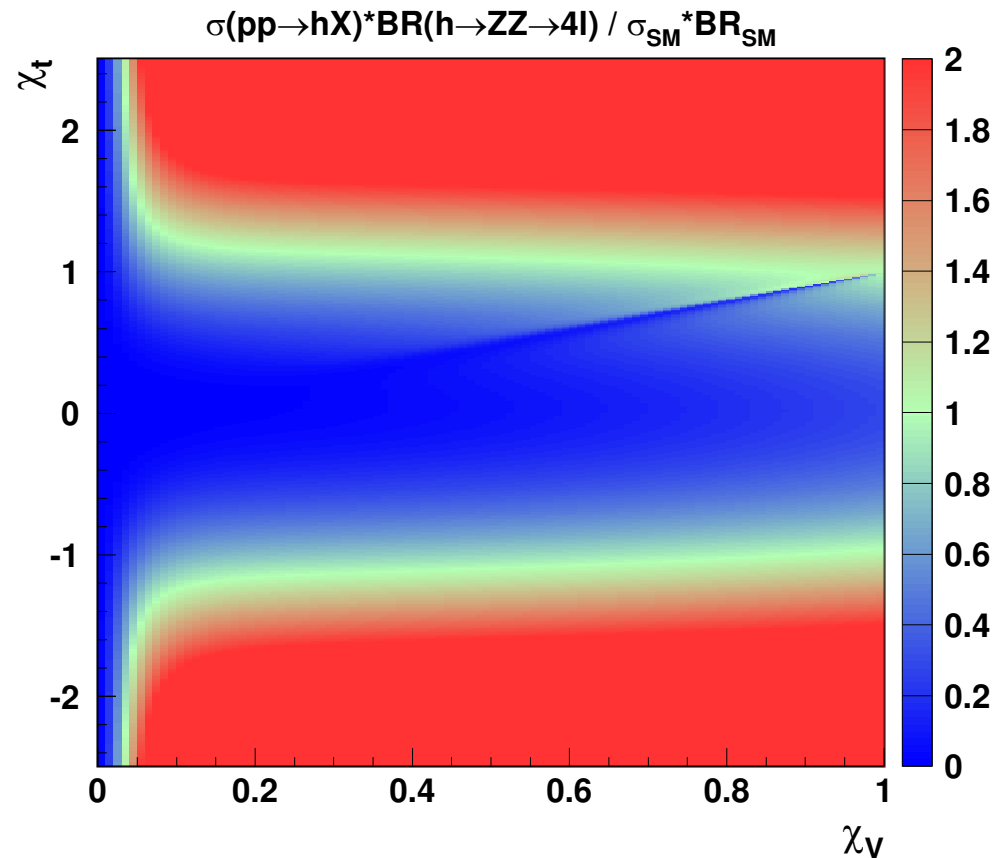
$$\sigma(pp \rightarrow hX) \cdot BR(h \rightarrow ZZ \rightarrow 4l)$$

“golden channel”

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

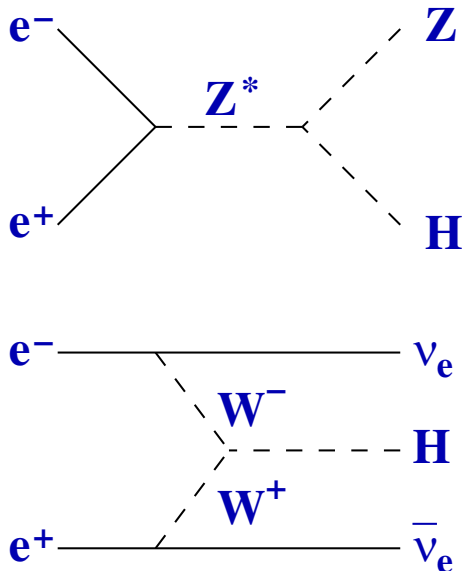
Precision $\sim 20\%$ expected

Cross section relative to SM



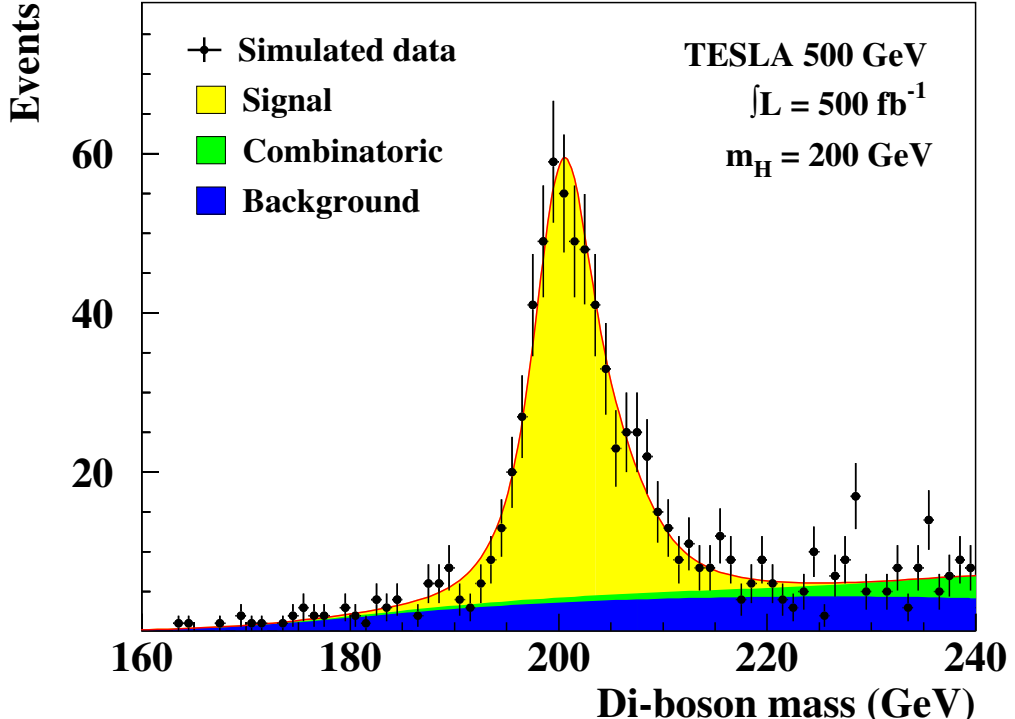
ILC

For Higgs boson production at TESLA
 ($\sqrt{s} = 500 \text{ GeV}, 500 \text{ fb}^{-1}$)
 two processes are considered



Production is sensitive only to χ_V

Expected mass distribution (SM)



N.Meyer, Eur. Phys. J. C35 (2004) 171
[hep-ph/0308142](https://arxiv.org/abs/hep-ph/0308142)



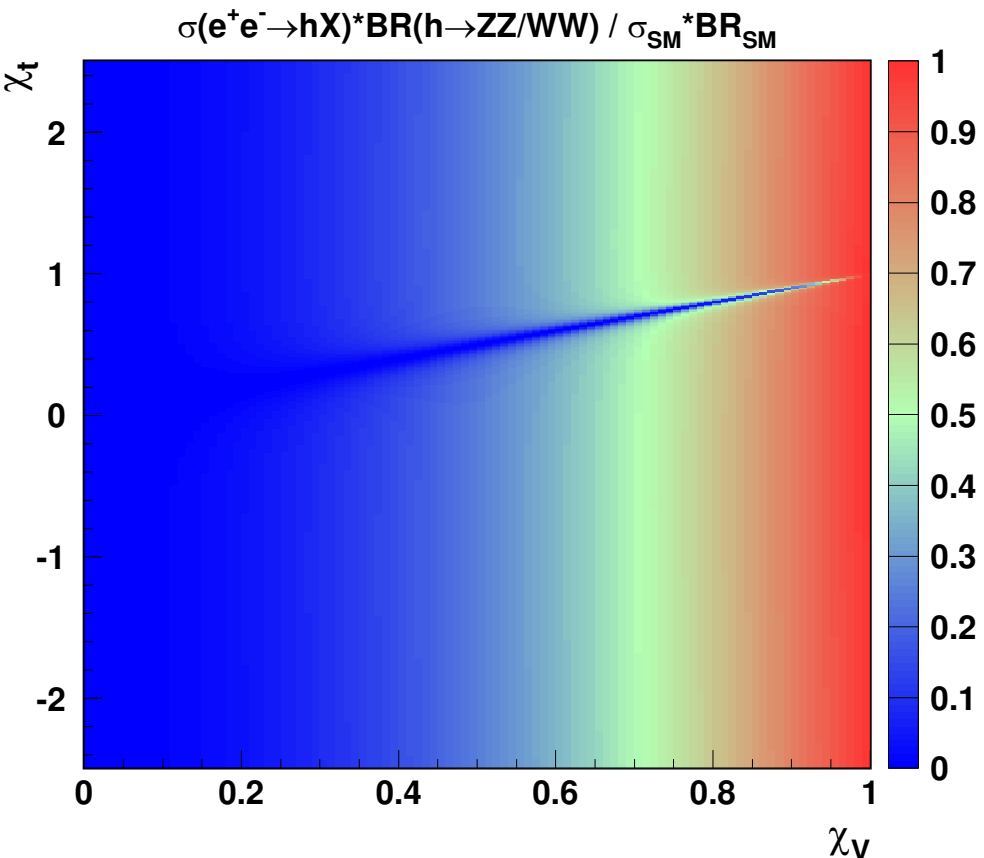
Measurement of the production cross section times branching ratio

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

is possible with precision $\sim 4 - 7\%$
(SM-like scenario, 500 fb^{-1})

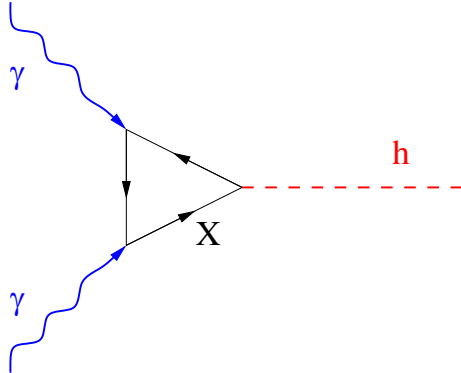
This will constrain the χ_V value

Cross section relative to SM



PLC

Cross section for the Higgs boson production at the **Photon Collider** is proportional to the **two-photon width**



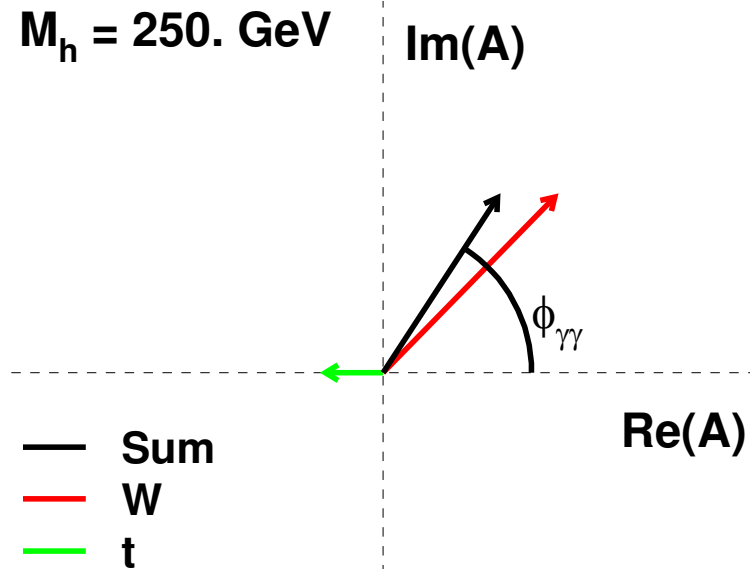
$$\Gamma(h \rightarrow \gamma\gamma) = \frac{G_F \alpha^2 M_h^3}{128 \sqrt{2} \pi^3} \cdot |\mathcal{A}|^2$$

where:

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

two-photon amplitude

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

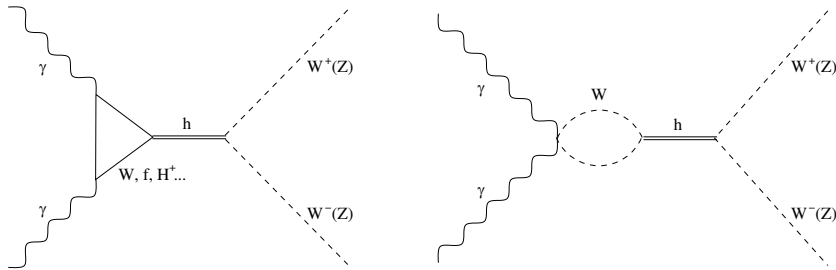


Phases of W^\pm and top contributions differ
Phase of top distribution changes with Φ_{HA} !

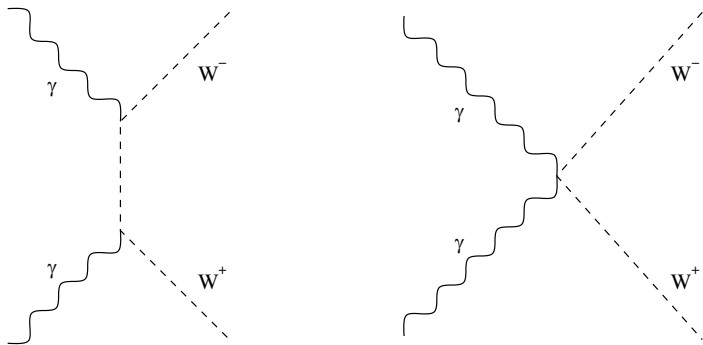
\Rightarrow Both $\Gamma_{\gamma\gamma}$ and the phase of the amplitude $\phi_{\gamma\gamma}$ depend on χ_V and χ_t

PLC

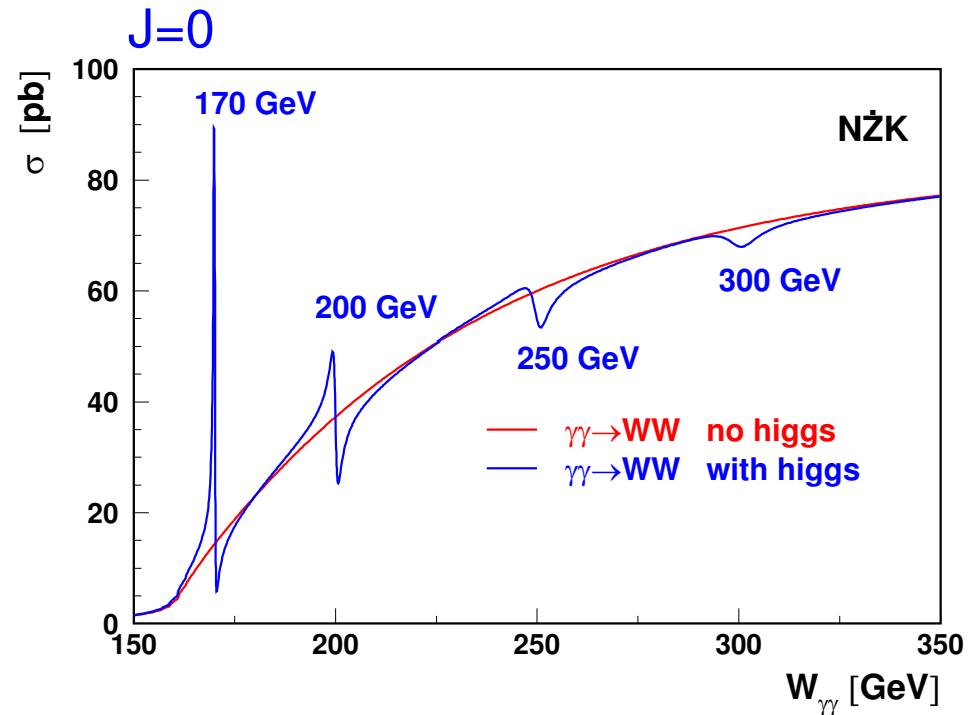
For **resonant** $\gamma\gamma \rightarrow h \rightarrow W^+W^-$ signal



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

PLC

Measurement of the production cross section times branching ratio

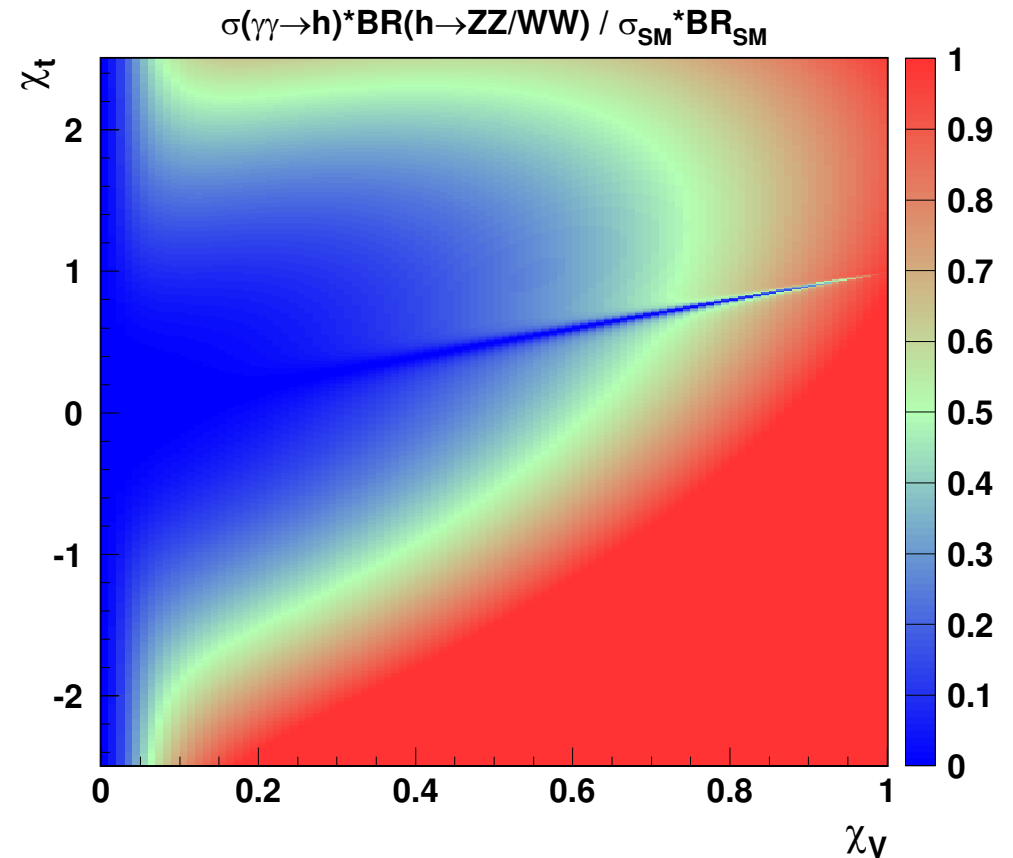
$$\sigma(\gamma\gamma \rightarrow h) \cdot BR(h \rightarrow WW/ZZ)$$

is possible with precision $\sim 4 - 9\%$

$\phi_{\gamma\gamma}$ can be measured with precision
40 – 120 mrad

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

Cross section relative to SM

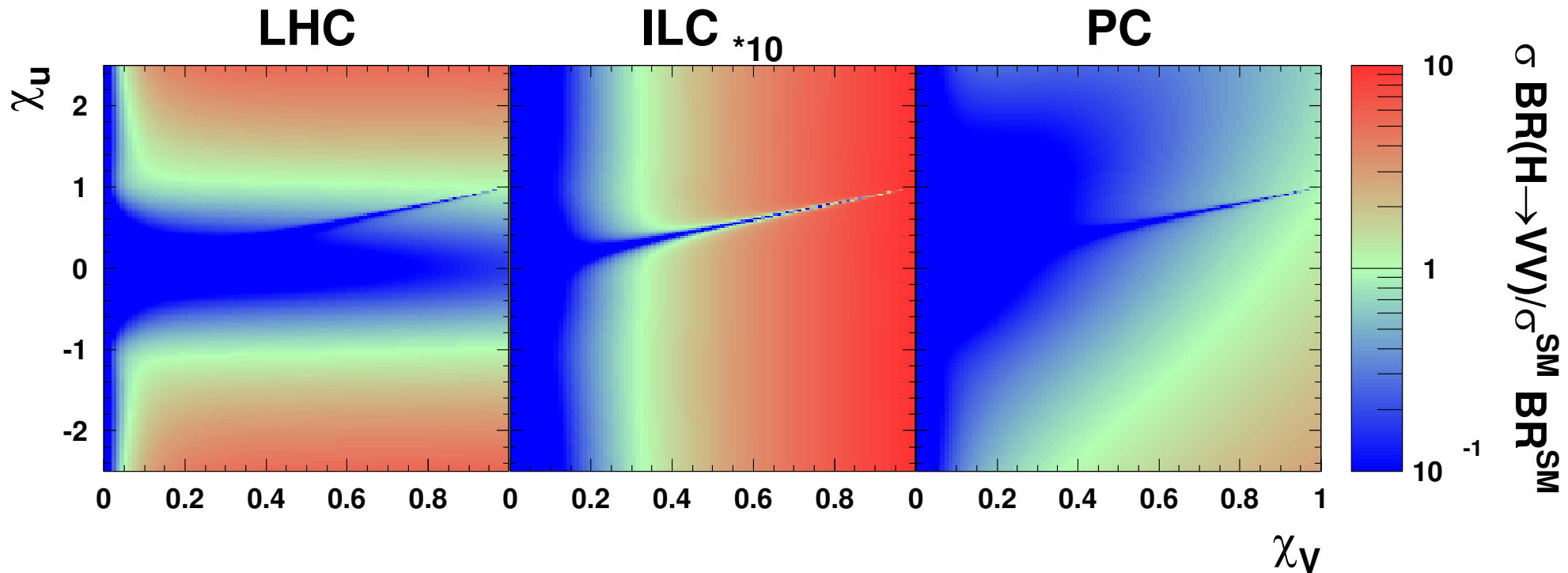


LHC ⊕ ILC ⊕ PC

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

Cross sections × BR relative to SM

$M_H = 250 \text{ GeV}$



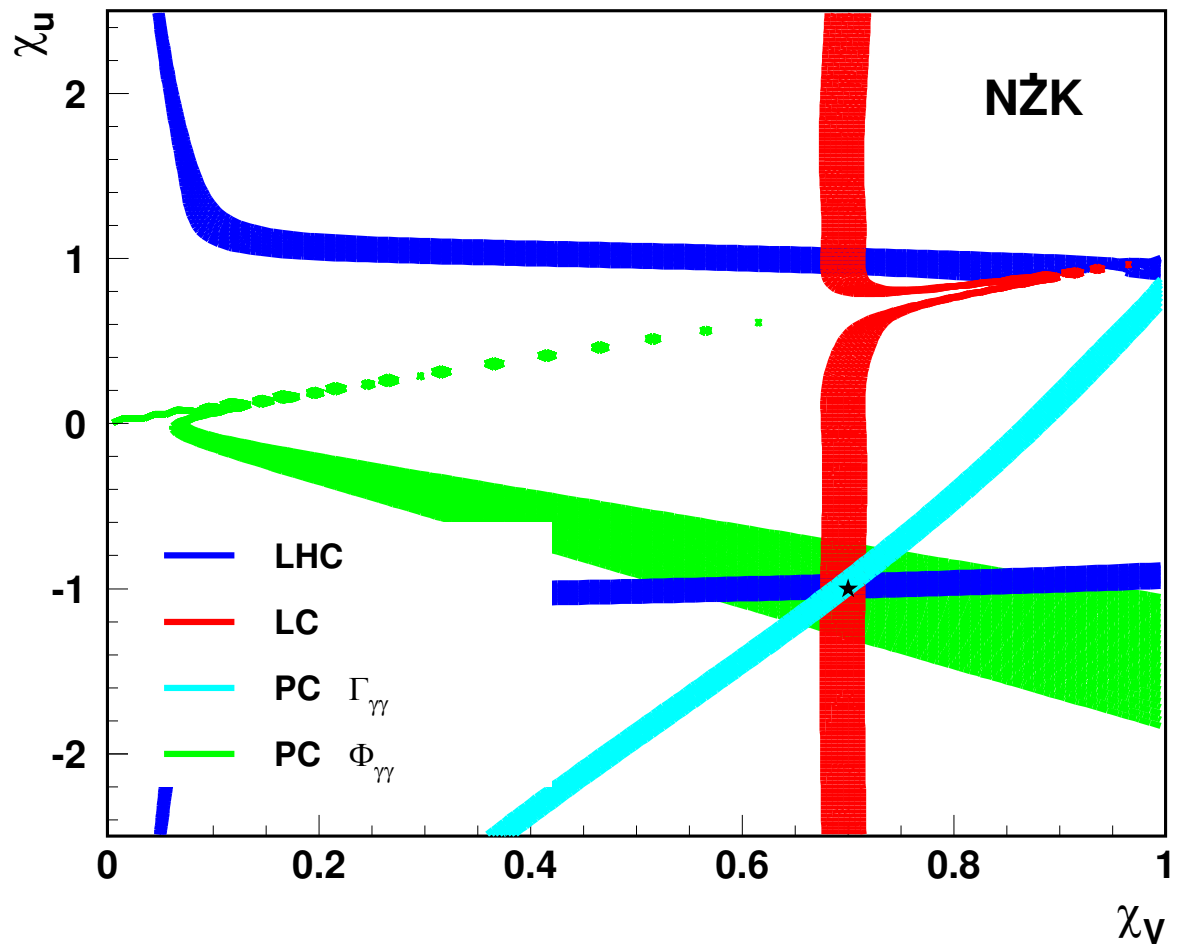
LHC ⊕ ILC ⊕ PC

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

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

statistical errors only

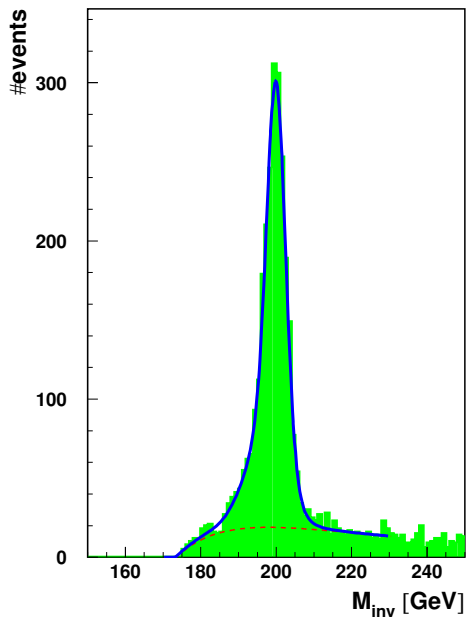
$$\chi_V = 0.7 \quad \chi_u = -1 \quad M_H = 250 \text{ GeV}$$



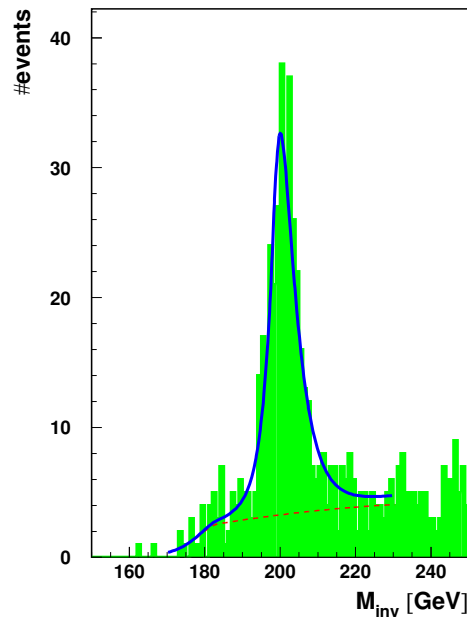
LHC ⊕ ILC ⊕ PC

Combined fit to the expected invariant mass distributions:

LHC

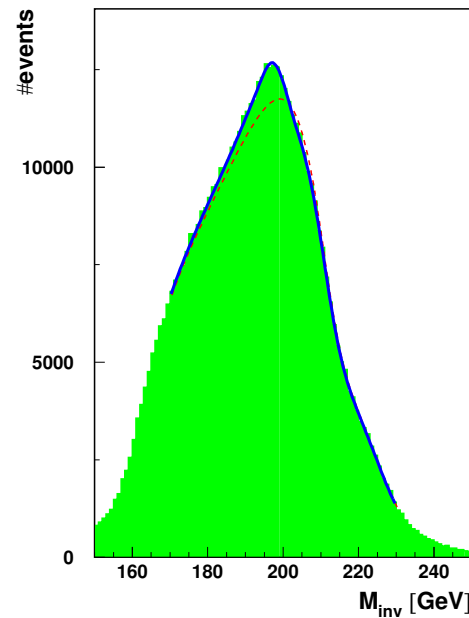


ILC



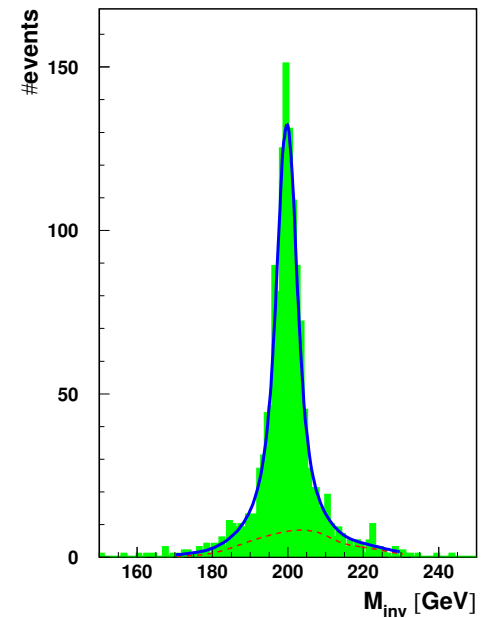
PC

$H \rightarrow WW$



PC

$H \rightarrow ZZ$



12 parameter fit: ● χ_V ● χ_u ● M_H ● Φ_{HA}

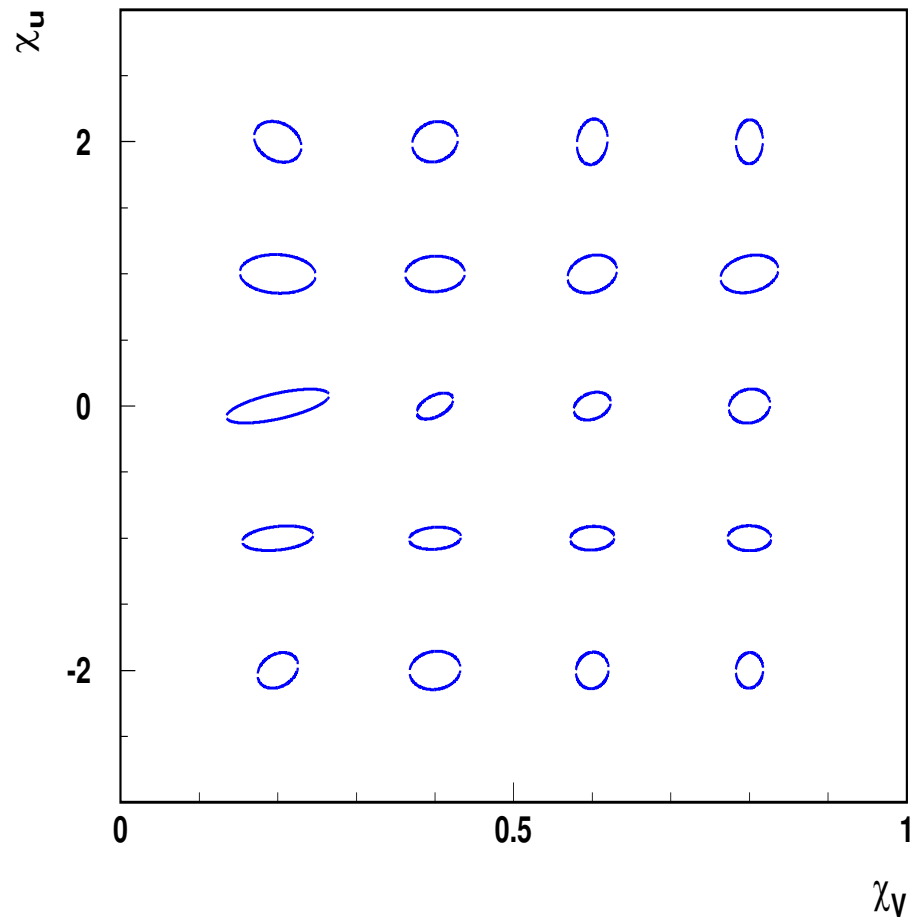
+ 8 normalization and $\gamma\gamma$ -spectra shape parameters (systematic uncertainties)

LHC ⊕ ILC ⊕ PC

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

1σ (stat.+sys.) contours

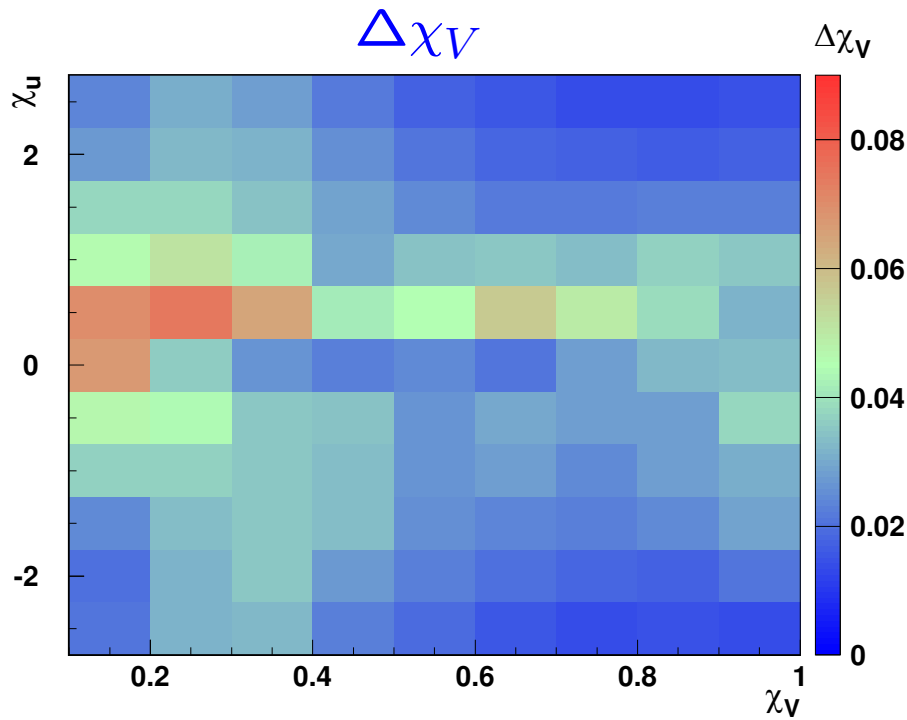
H couplings to vector bosons (χ_V) and up fermions (χ_u) for $M_H = 250$ GeV



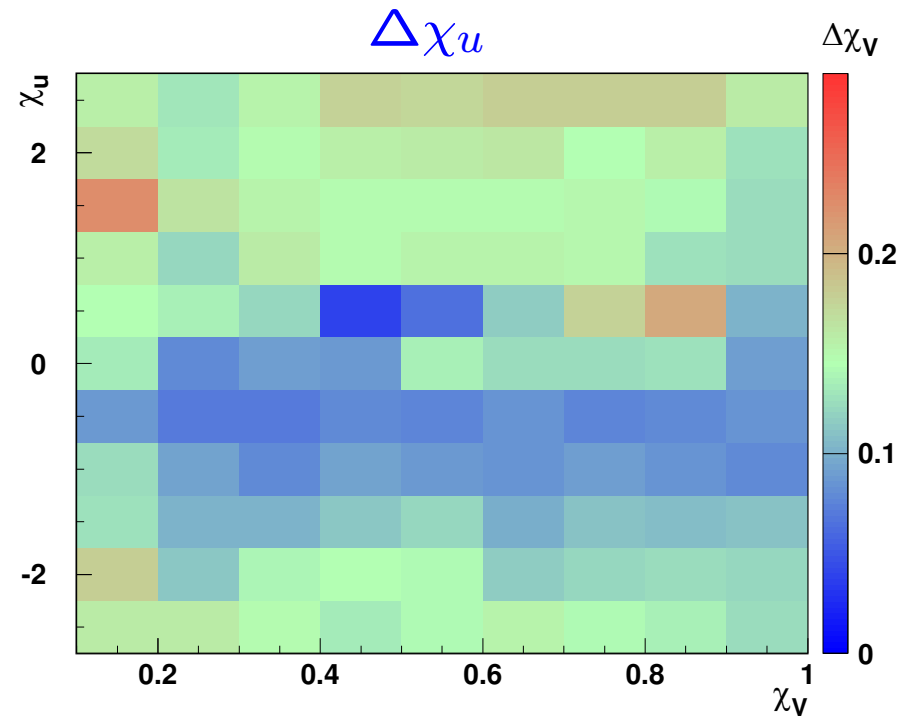
LHC ⊕ ILC ⊕ PC

Coupling errors

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



$$\langle \Delta\chi_V \rangle = 0.03$$



$$\langle \Delta\chi_u \rangle = 0.13$$

LHC ⊕ ILC ⊕ PC

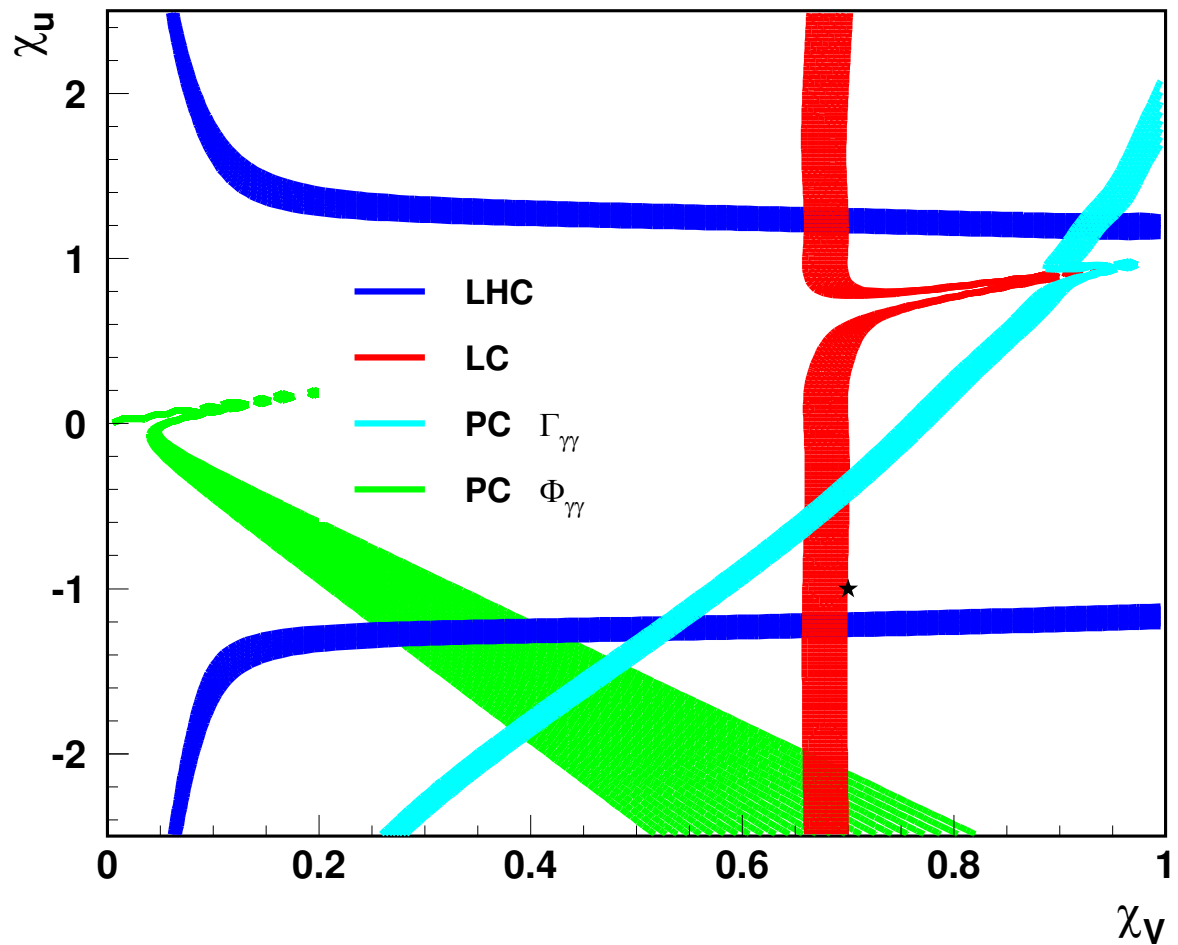
Allowed coupling values from **cross section** measurements at **LHC**, **ILC** and **PC**, and the phase measurement at **PC**.

Measurements compared assuming **CP-conserving 2HDM(II)** not consistent ⇒ “new physics”:

- different **coupling structure** (eg. CP violation)
- existence of **new heavy particles** contributing to Γ_{gg} and $\Gamma_{\gamma\gamma}$

$$\chi_V = 0.7 \quad \chi_u = -1 \quad \Phi_{HA} = -0.2$$

NŻK



2HDM (II) with CP violation

$H - A$ mixing

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:

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

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

⇒ see our paper JHEP 0502:041,2005 [hep-ph/0403138]

In general case

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

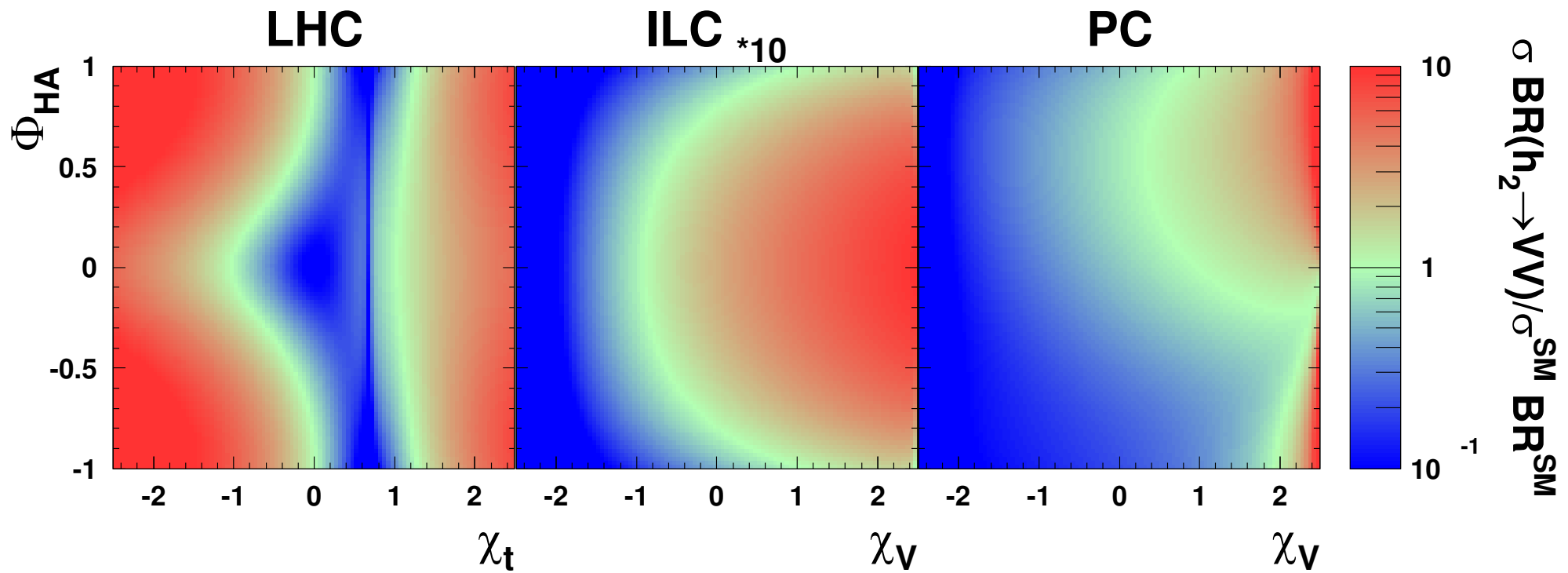
We consider h_2 production and decays, for $|\Phi_{HA}| \ll 1$ (weak CP violation)

LHC ⊕ ILC ⊕ PC

Sensitivity of LHC, ILC and Photon Collider measurements to CP-violating mixing phase Φ_{HA}

Cross sections \times BR relative to SM

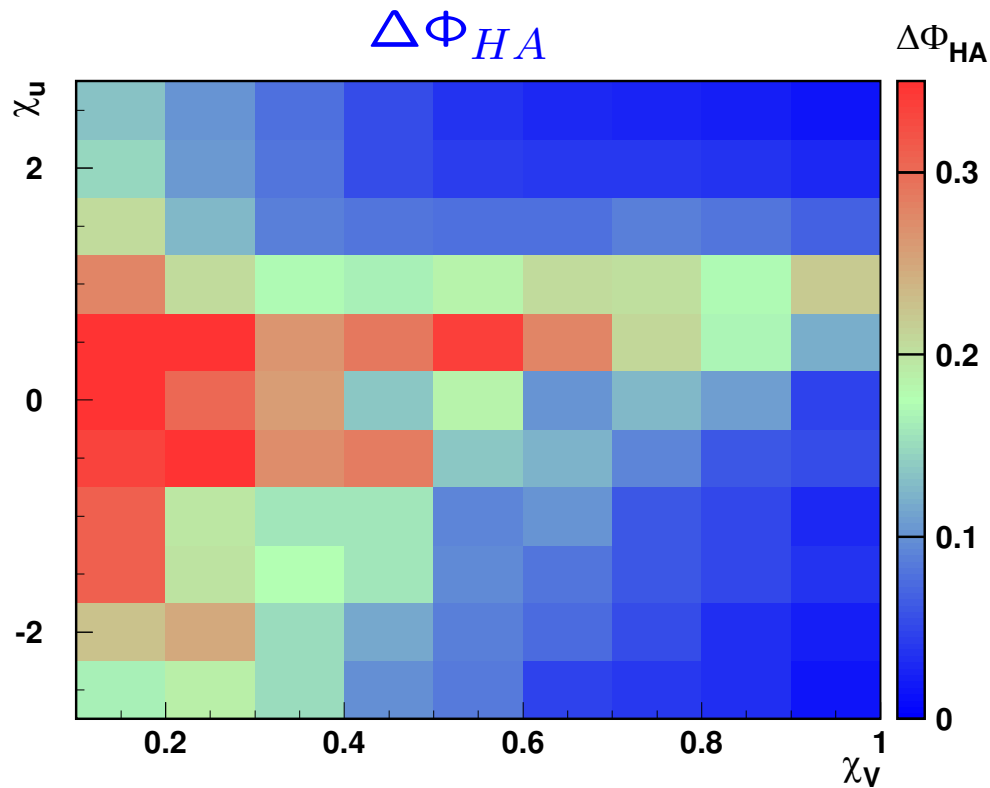
$M_H = 250 GeV$



LHC ⊕ ILC ⊕ PC

Φ_{HA} error

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



For a wide range of couplings

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

Determination of Φ_{HA} not possible
without **Photon Collider** data

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

CP conserving 2HDM (II)

Higgs boson couplings

Scalar Higgs bosons h and H
with basic couplings (relative to SM):

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

	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

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

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

Also couplings of h can be expressed in terms of

$$\chi_V^H \text{ and } \chi_u^H$$

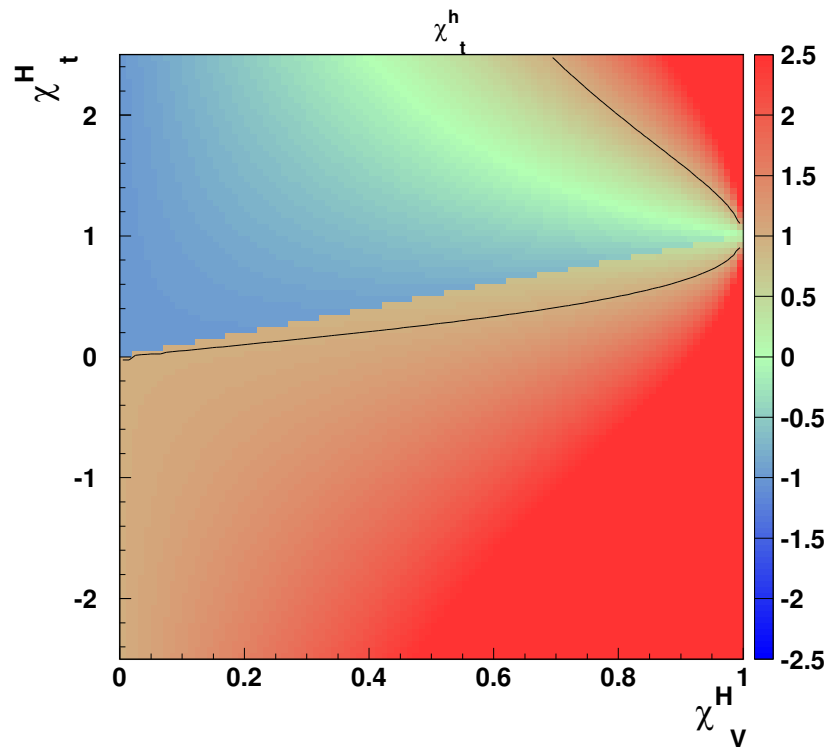
We can try to combine h and H measurements...

CP conserving 2HDM (II)

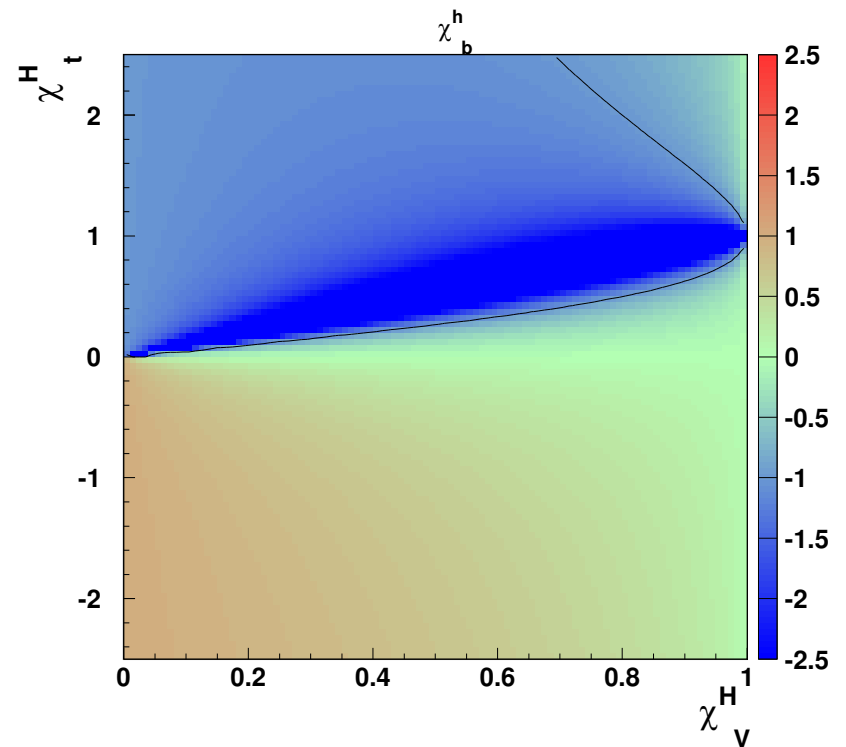
Light Higgs boson couplings

As a function of the heavy scalar Higgs boson couplings χ_V^H and χ_u^H

Coupling to up-type fermions



Coupling to down-type fermions



Light Higgs boson production

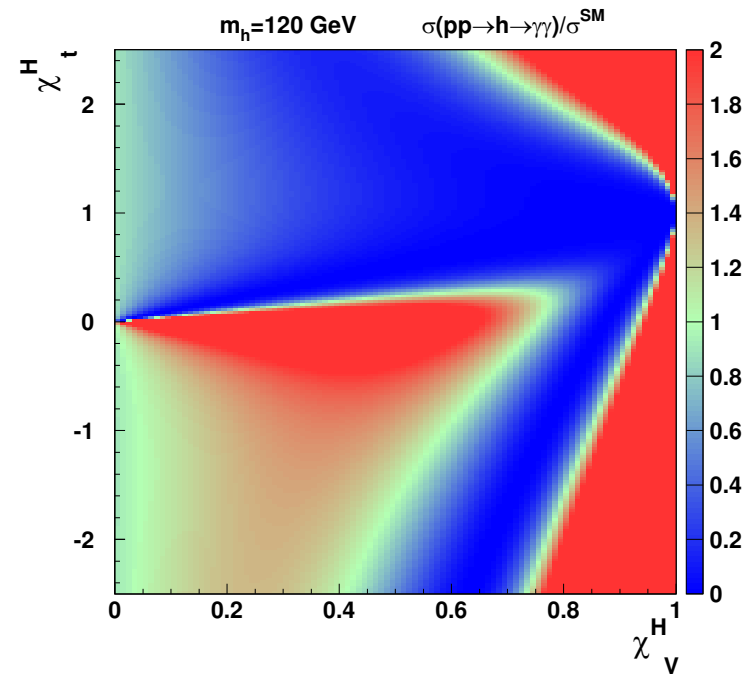
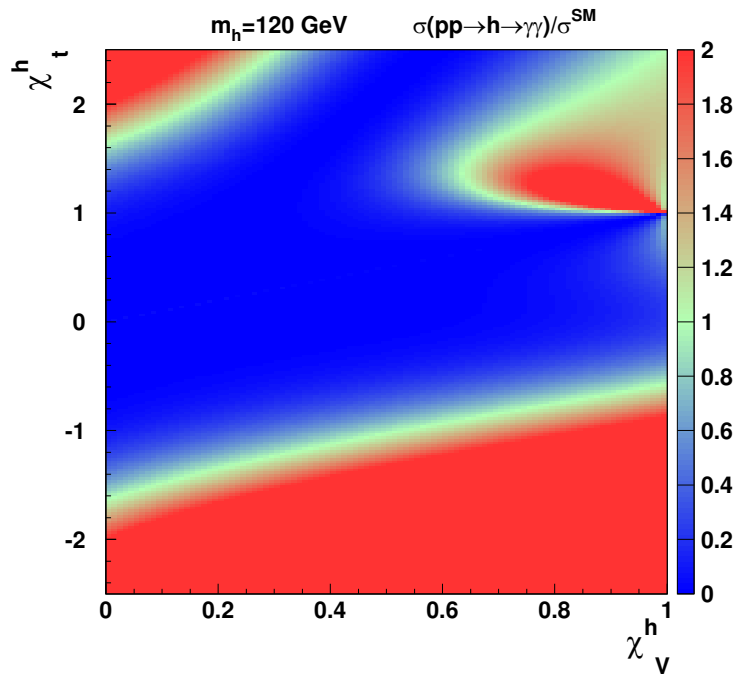
LHC

The most promising channel for SM-like boson is $pp \rightarrow h X \rightarrow \gamma\gamma X$ (CMS)

Cross sections \times BR relative to SM as a function of

h couplings

H couplings



$M_h = 120$ GeV

Light Higgs boson production

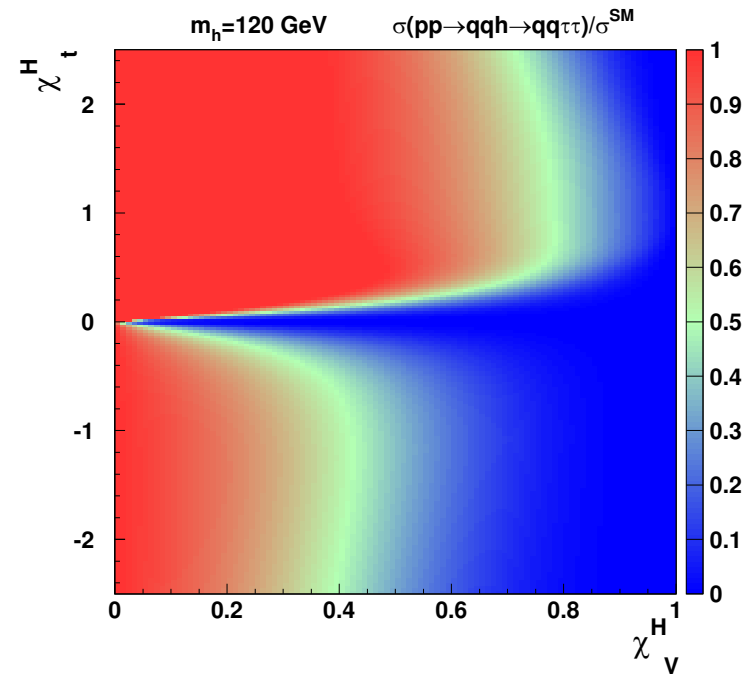
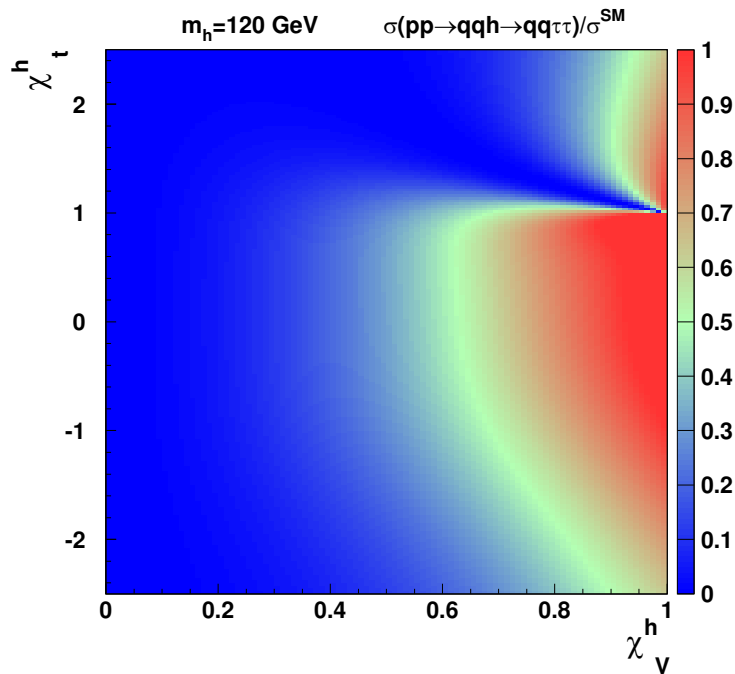
ILC

For SM-like boson we can measure the cross section for $e^+e^- \rightarrow h Z \rightarrow b\bar{b} X$

Cross sections \times BR relative to SM as a function of

h couplings

H couplings



Same cross section \times BR dependence for $pp \rightarrow qq h \rightarrow qq \tau\tau$ at LHC

Light Higgs boson production

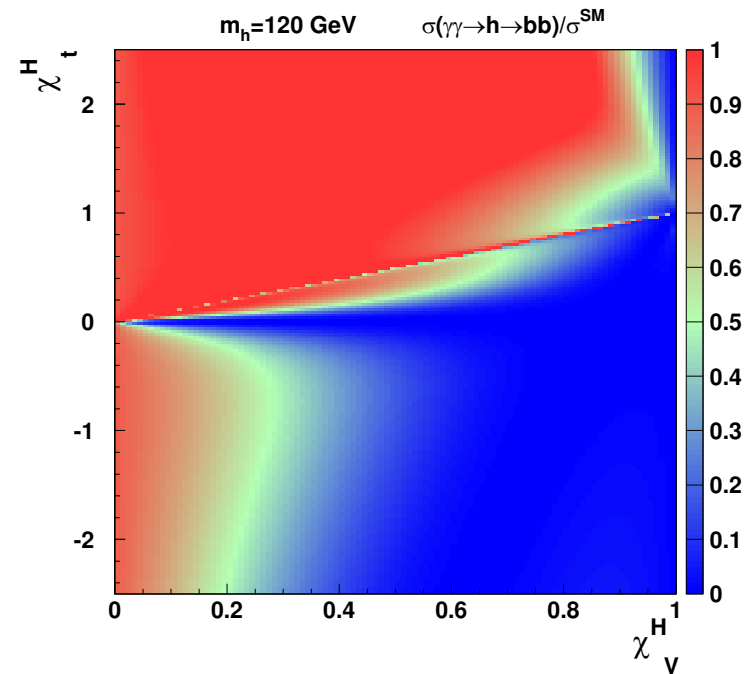
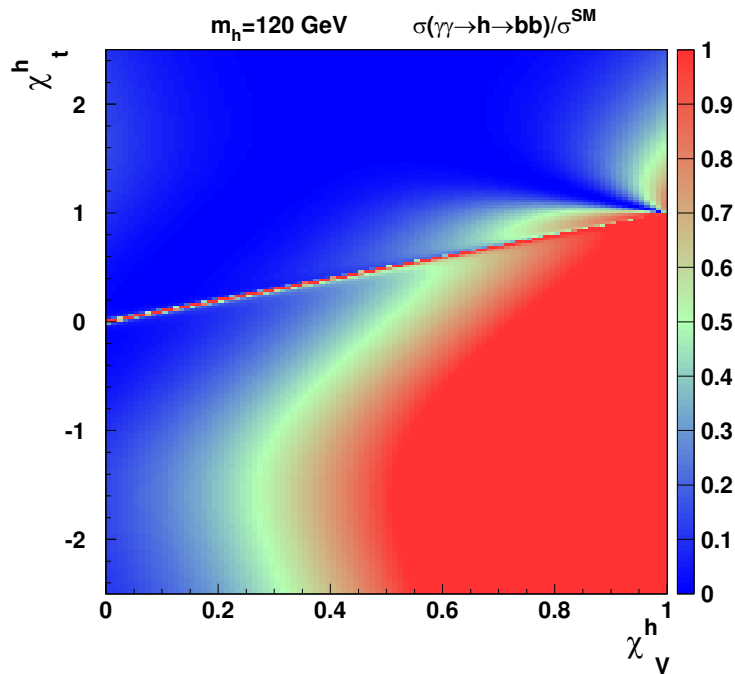
PLC

At the Photon Collider we precisely determine the cross section for $\gamma\gamma \rightarrow h \rightarrow b\bar{b}$

Cross sections \times BR relative to SM as a function of

h couplings

H couplings



$M_h = 120$ GeV

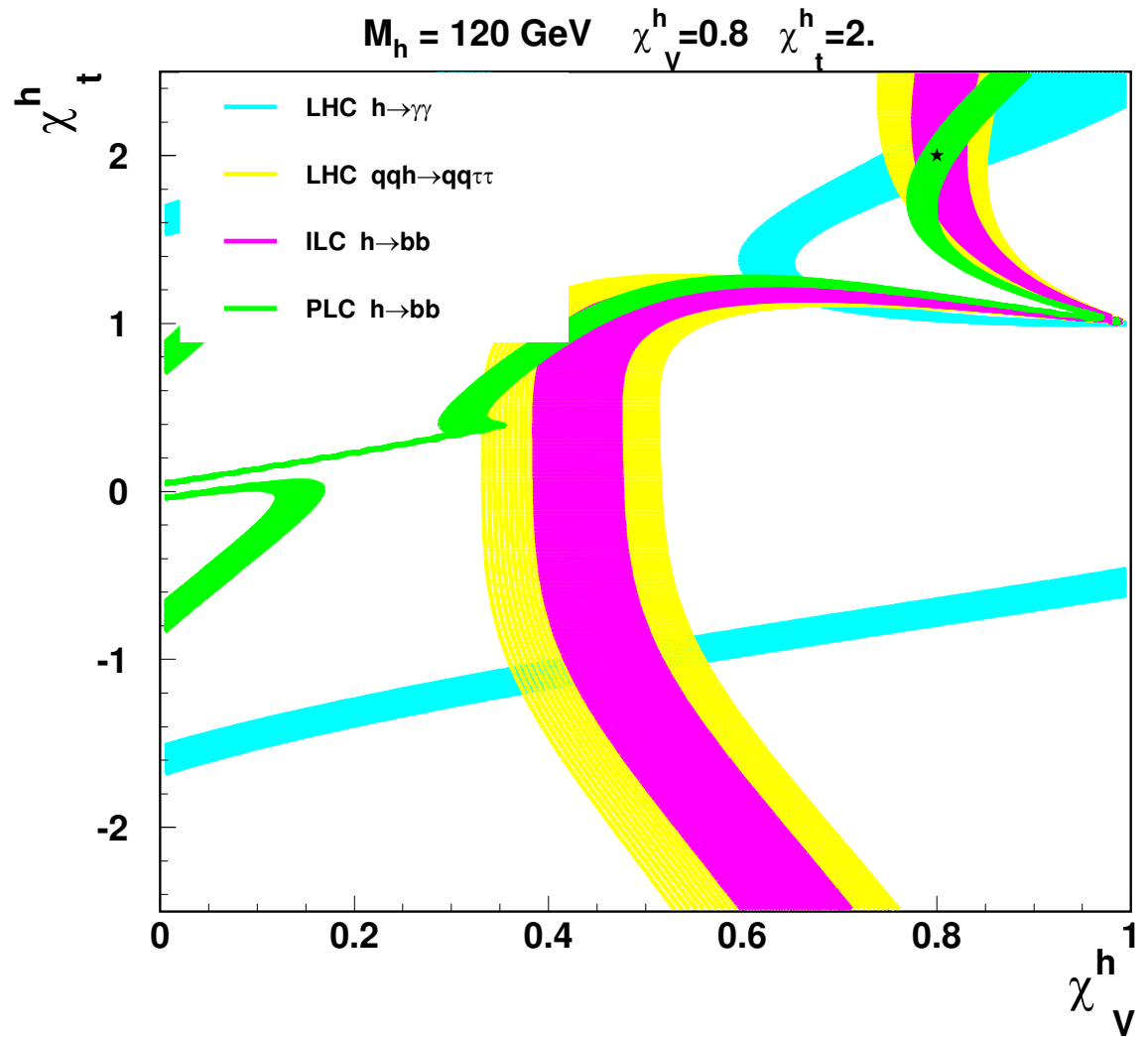
Light Higgs boson production

LHC ⊕ ILC ⊕ PLC

Allowed coupling values from light Higgs boson production cross section measurements at LHC, ILC and PC.

As a function of h couplings

$M_h = 120$ GeV

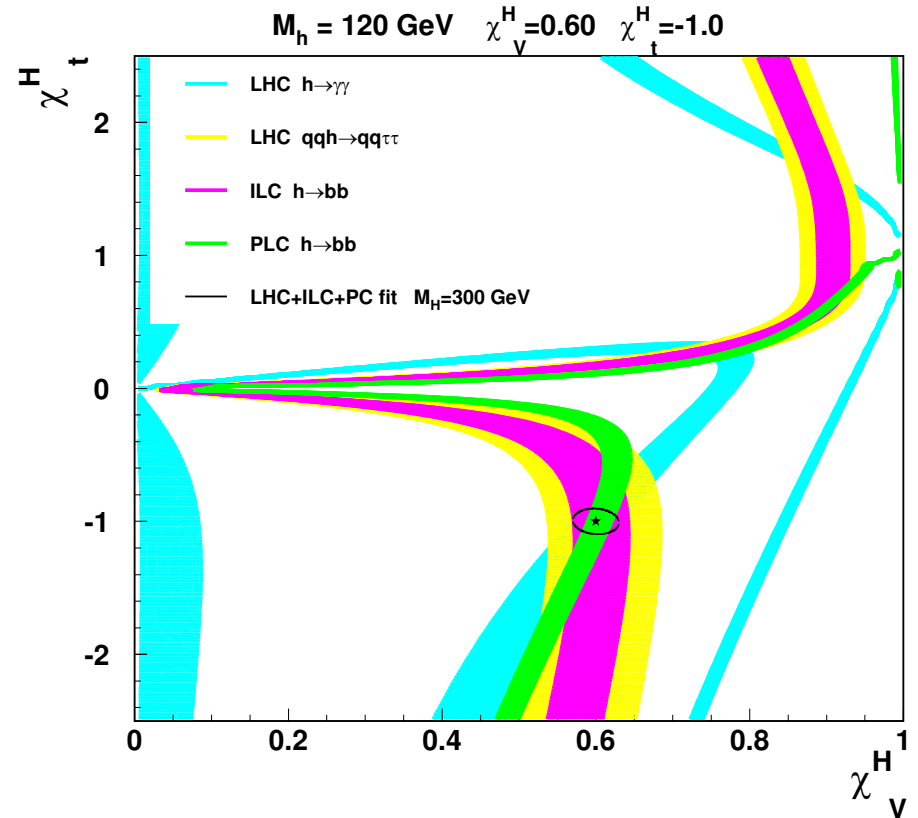
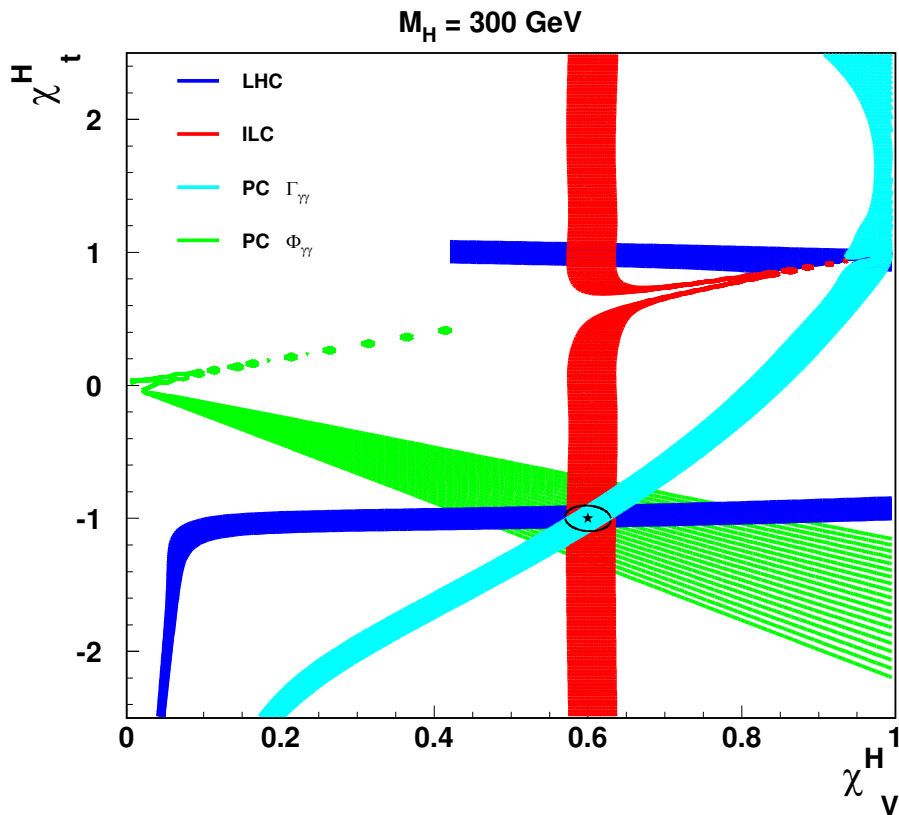


Light Higgs boson production

LHC ⊕ ILC ⊕ PLC ⊗ $h ⊕ H$

Allowed heavy scalar Higgs boson coupling values from measurements of
heavy Higgs boson

light Higgs boson



Summary

Heavy **Higgs** boson production and decays to **WW/ZZ** studied for masses between **200** and **350 GeV**.

2HDM(II) considered, without and with (weak) **CP violation**

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

Only the **combined analysis** of LHC, ILC 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**.

Determination of **heavy** scalar Higgs boson couplings from LHC, ILC and PC measurements and be compared to measurements of **light** Higgs boson production \Rightarrow **test of the coupling structure** of the model.

Systematic uncertainties

LHC ⊕ ILC ⊕ PC analysis

Parameters used in the combined fit, in addition to χ_V , χ_u , Φ_{HA} and M_H

Parameter:

- signal normalization for pp
- background normalization for pp
- signal normalization for e^+e^-
- background normalization for e^+e^-
- signal normalization for $\gamma\gamma$
- background normalization for $\gamma\gamma$
- $\gamma\gamma$ spectra shape

Assumed uncertainty:

- ⇒ 20% uncertainty
- ⇒ 10% uncertainty
- ⇒ 5% uncertainty
- ⇒ 5% uncertainty
- ⇒ 5% uncertainty
- ⇒ 10% uncertainty
- ⇒ 10% uncertainty
(parametrized by 2 parameters)

PLC

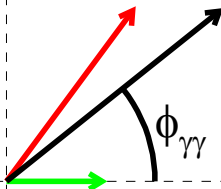
Contributions from W^\pm and top loops to the two-photon amplitude:

CP-conserving 2HDM (II)

$$\chi_V = 0.7, \chi_t = -1$$

$$M_h = 300. \text{ GeV}$$

Im(A)



Re(A)

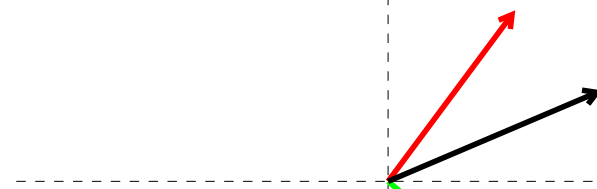
— SM
— W
— t

2HDM (II) with weak CP violation

$$\chi_V = 0.7, \chi_t = -1, \Phi_{HA} = -0.2$$

$$M_h = 300. \text{ GeV}$$

Im(A)



Re(A)

— SM
— W
— t

Significant change both in $\Gamma_{\gamma\gamma}$ and in $\phi_{\gamma\gamma}$