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

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Warszawa

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NŻK

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Outline

- Higgs couplings in 2HDM (II)
- Higgs production at LHC, ILC, and PLC
- Combined analysis
- 2HDM (II) with CP violation

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

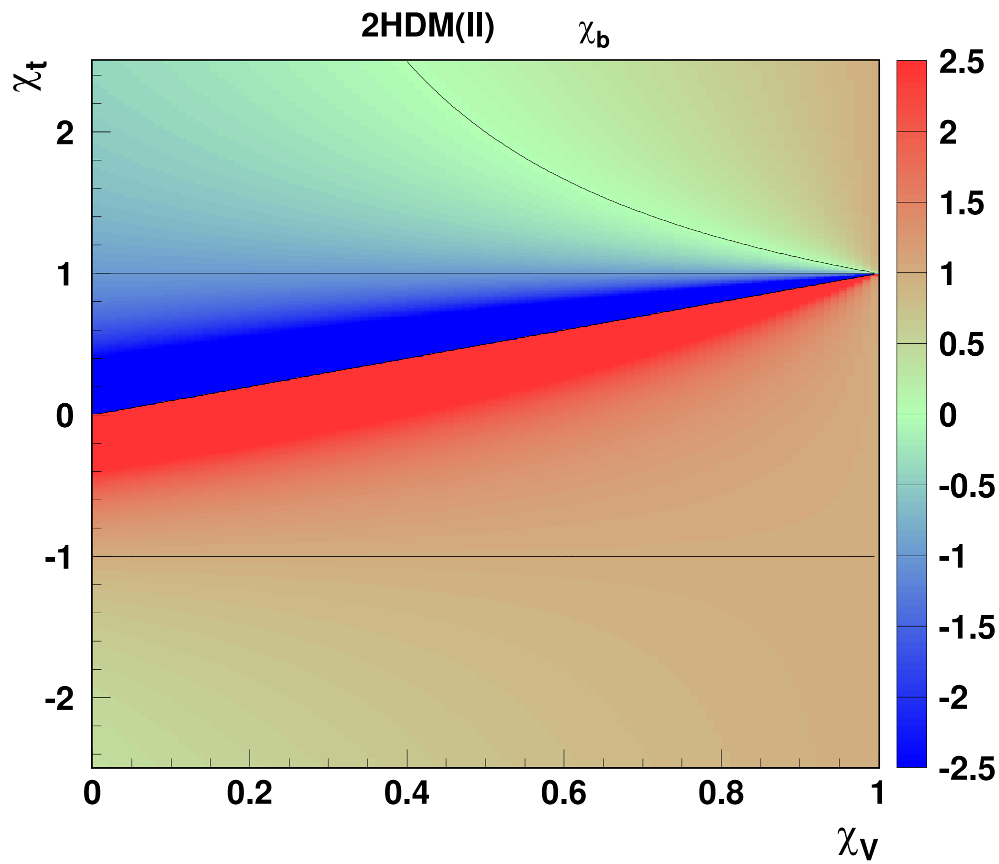
$$0 \leq \chi_V \leq 1$$

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

2HDM (II)

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

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

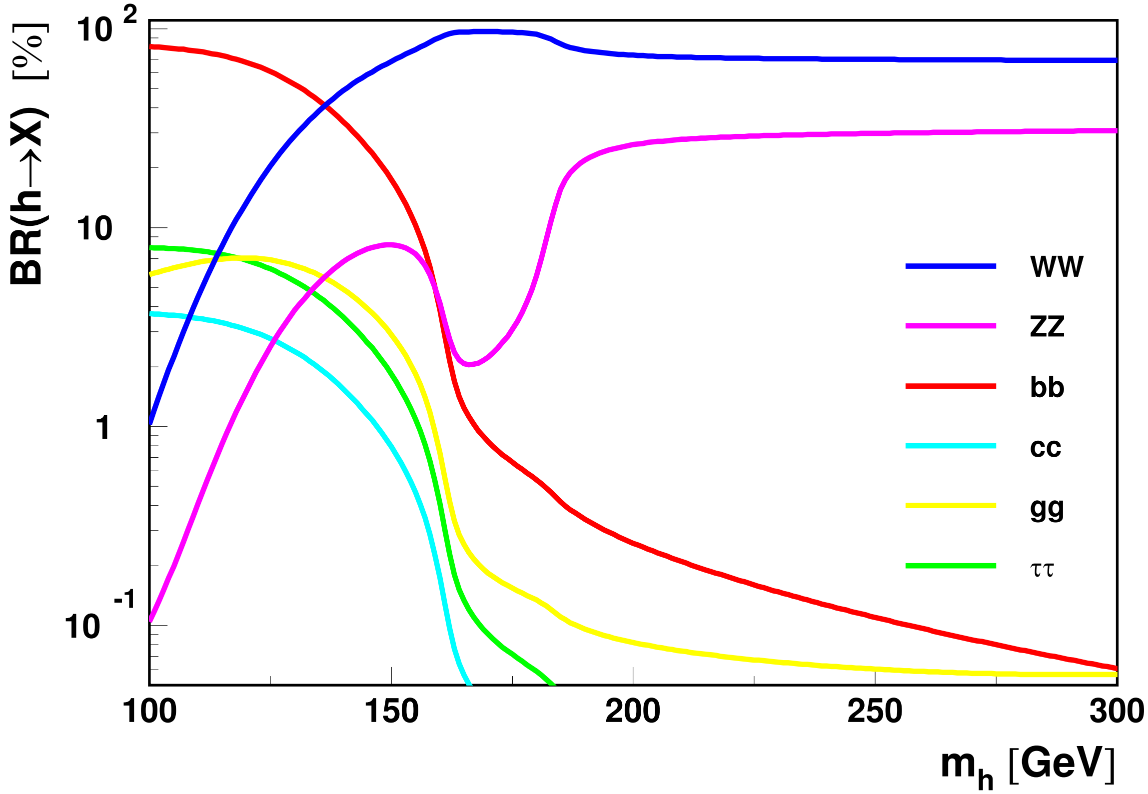


2HDM (II)

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.

SM branching ratios



LHC

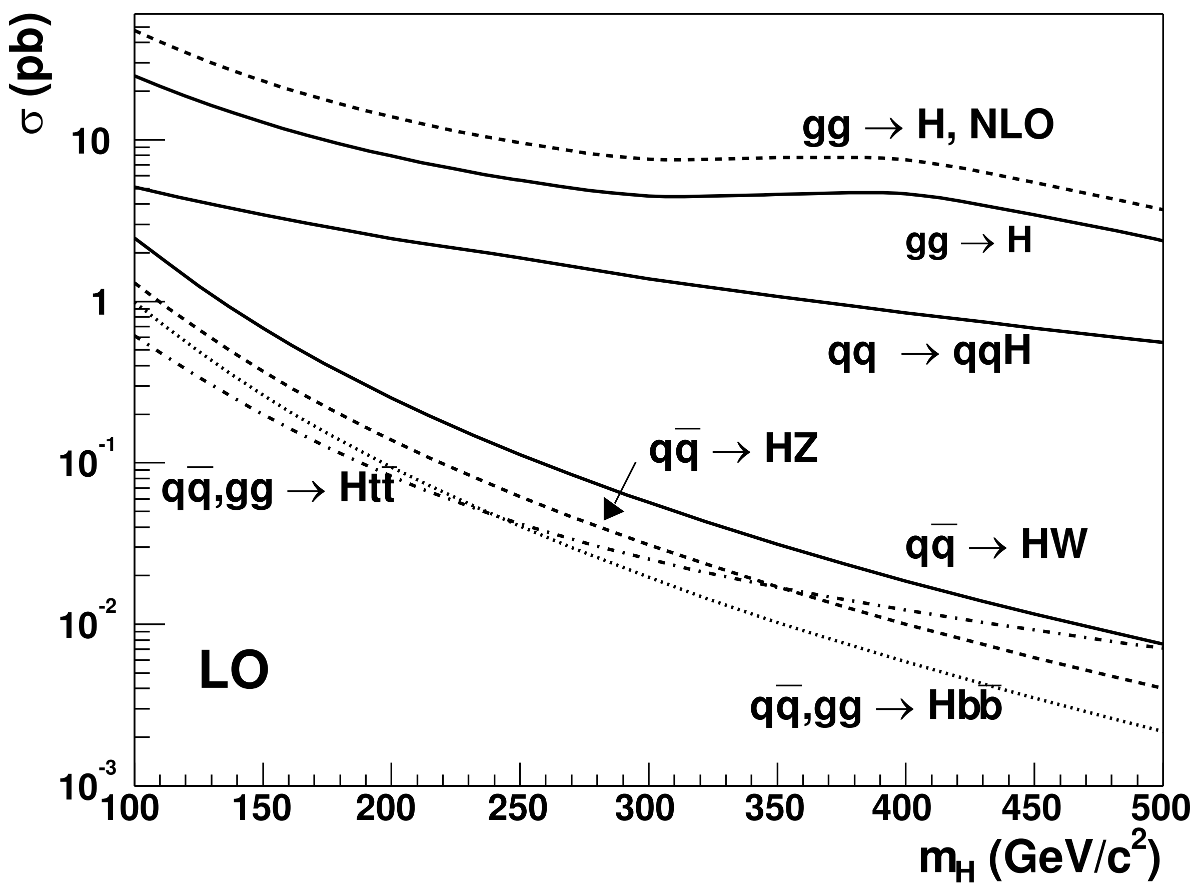
In the considered mass range Higgs boson production at LHC is dominated by the gluon fusion process.

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

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

"golden channel"

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

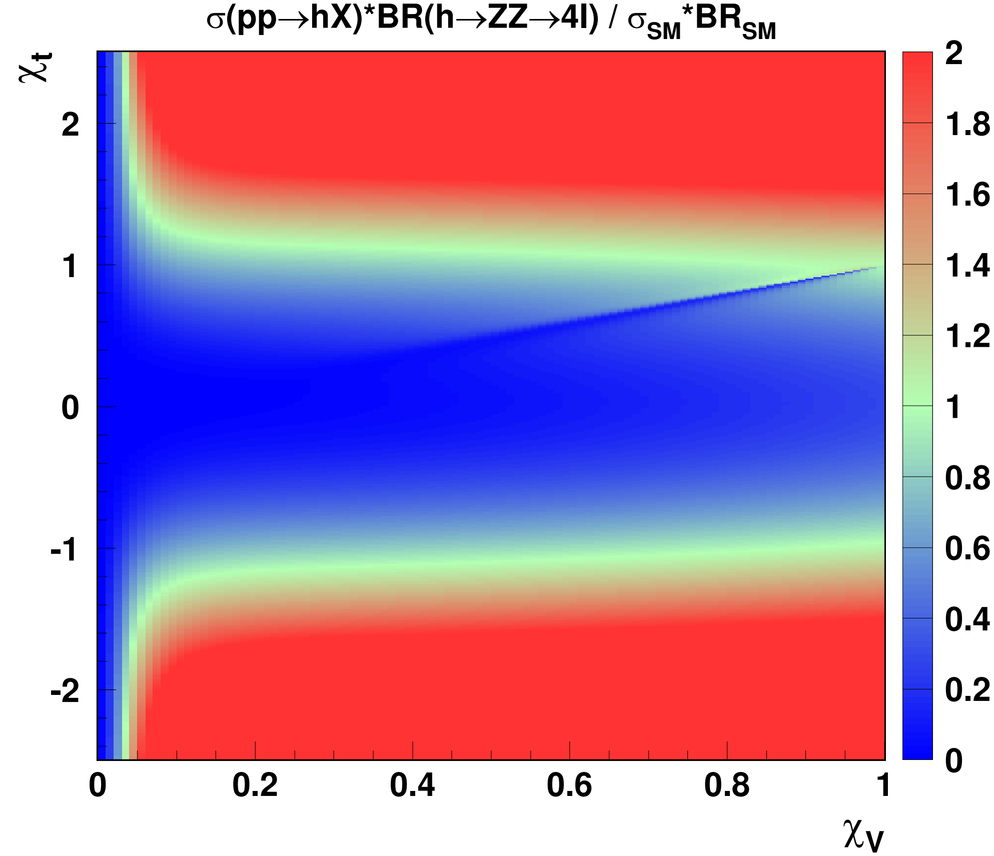
We use results of

C.P.Buszello, I.Fleck, P.Marquard, J.J. van der Bij, Eur. Phys. J. C32(2004)209

hep-ph/0212396

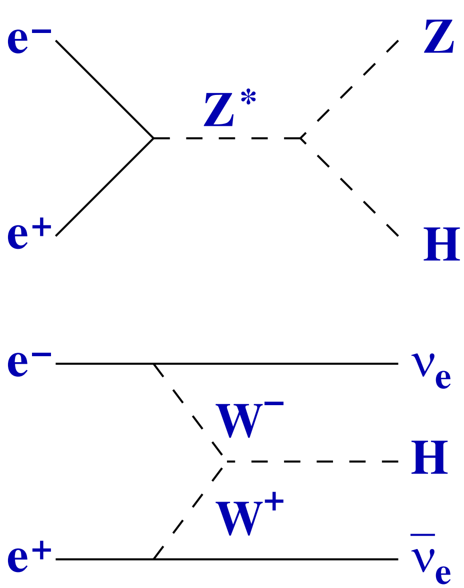
Precision $\sim$ 15% expected

Cross section relative to SM



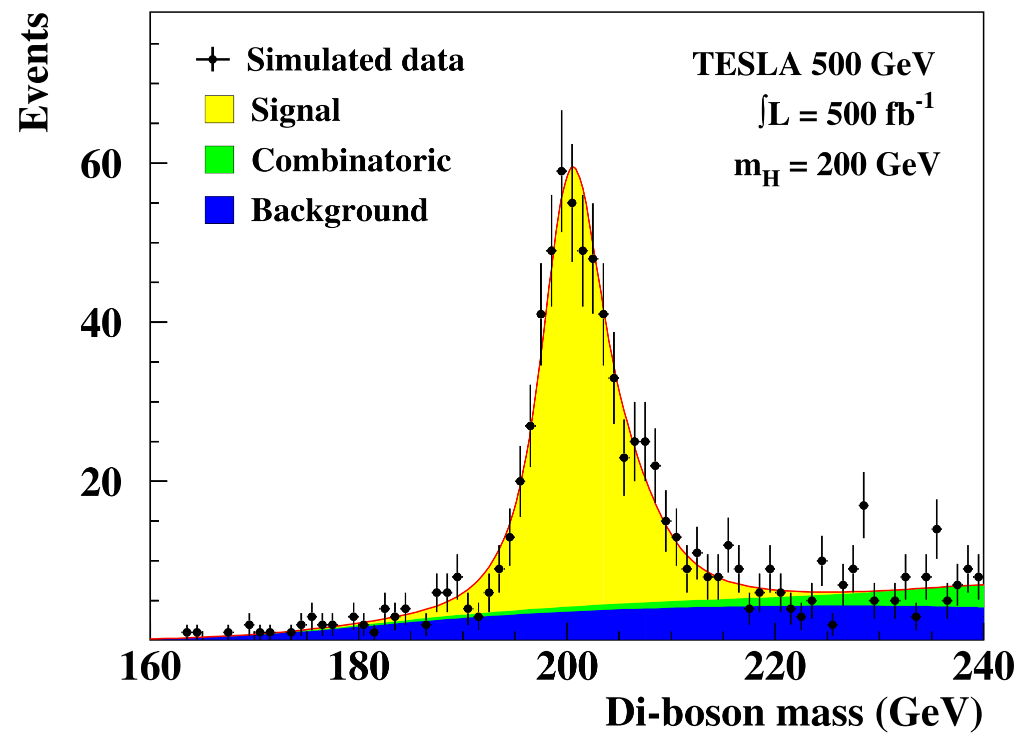
ILC

For Higgs boson production at TESLA
($\sqrt{s} = 500\ GeV$, 500 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

ILC

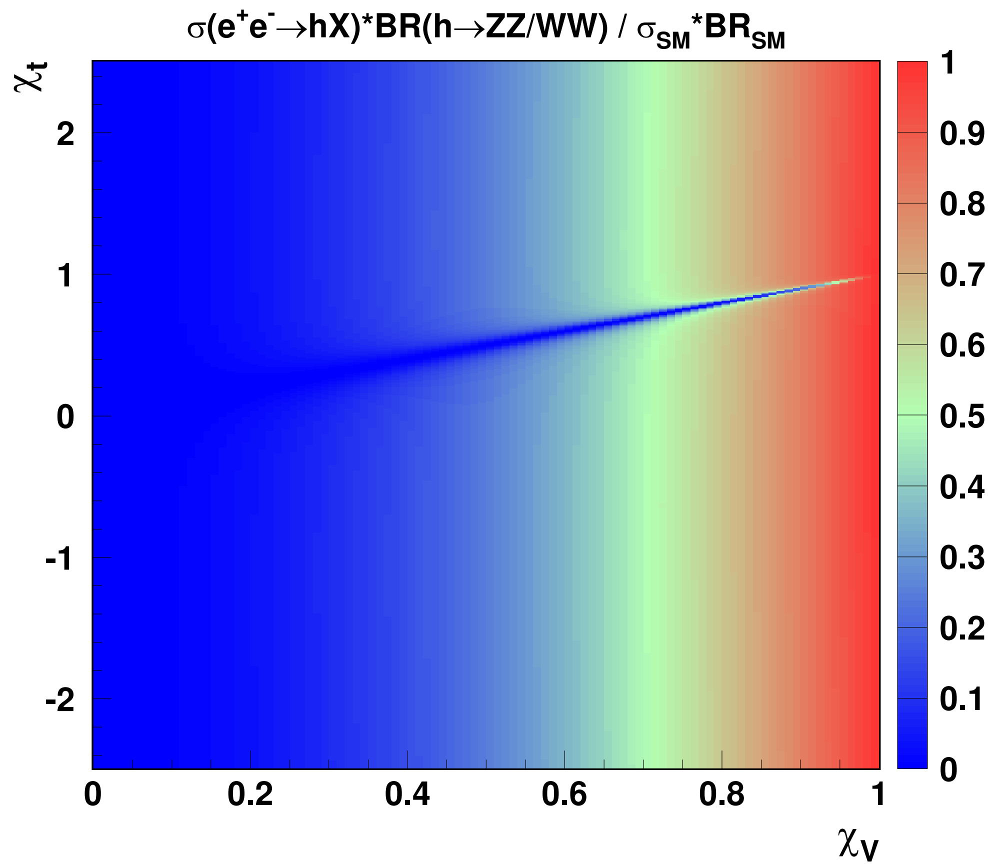
Measurement of the production cross section times branching ratio

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

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

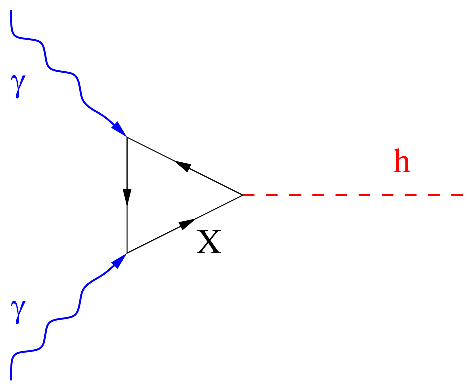
This will constrain the χ_V value

Cross section relative to SM



PLC

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



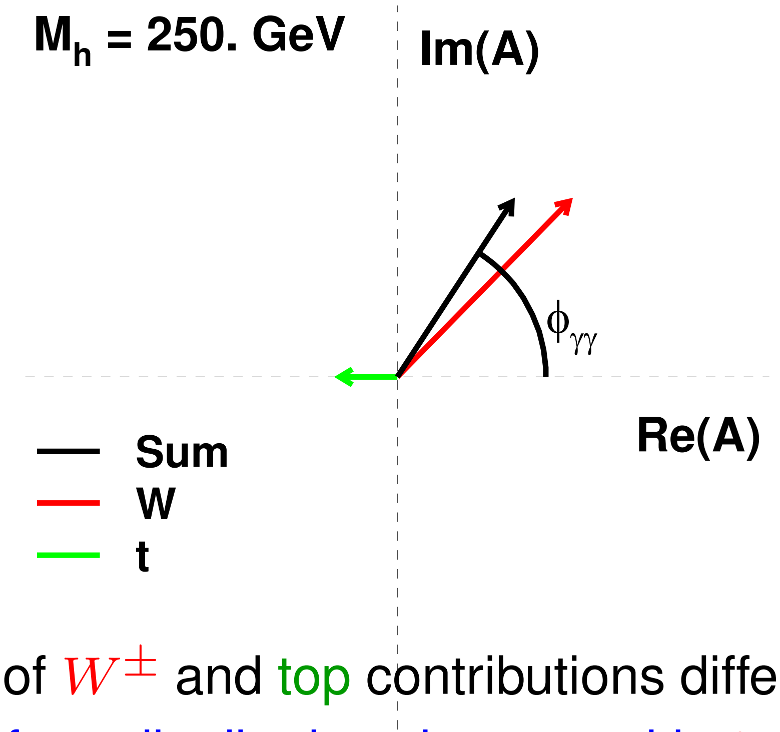
$$\Gamma(h \rightarrow \gamma\gamma) \;=\; \frac{G_F \alpha^2 M_h^3}{128\sqrt{2}\,\pi^3} \cdot |\mathcal{A}|^2$$

where:

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

two-photon amplitude

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



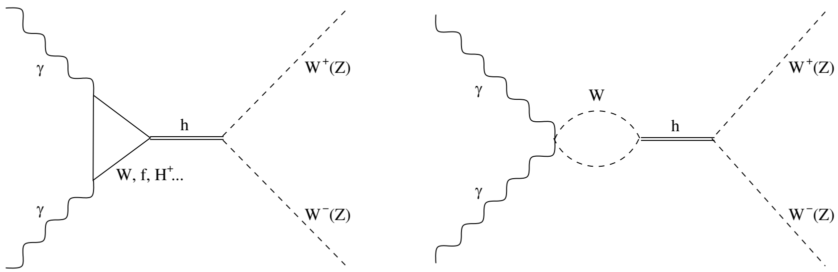
Phases of $W^\pm$ and top contributions differ

Phase of top distribution changes with Φ_{HA} !

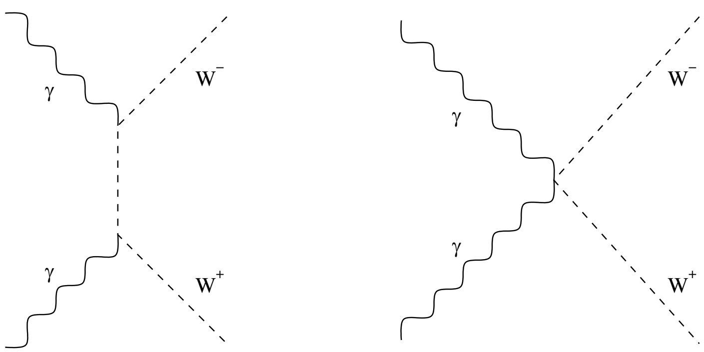
$\Rightarrow$ Both $\Gamma_{\gamma\gamma}$ and the phase of the amplitude $\phi_{\gamma\gamma}$ depend on χ_V and χ_t

PLC

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

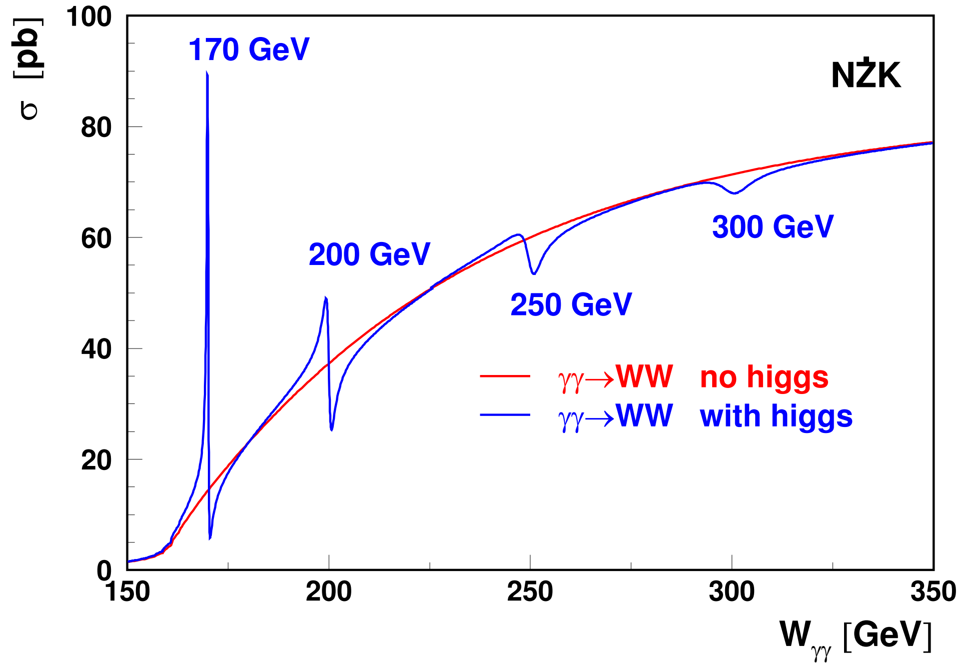


there is a large non-resonant bg.



Large interference effects are expected in the considered mass range

J=0



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

PLC

Measurement of the production cross section times branching ratio

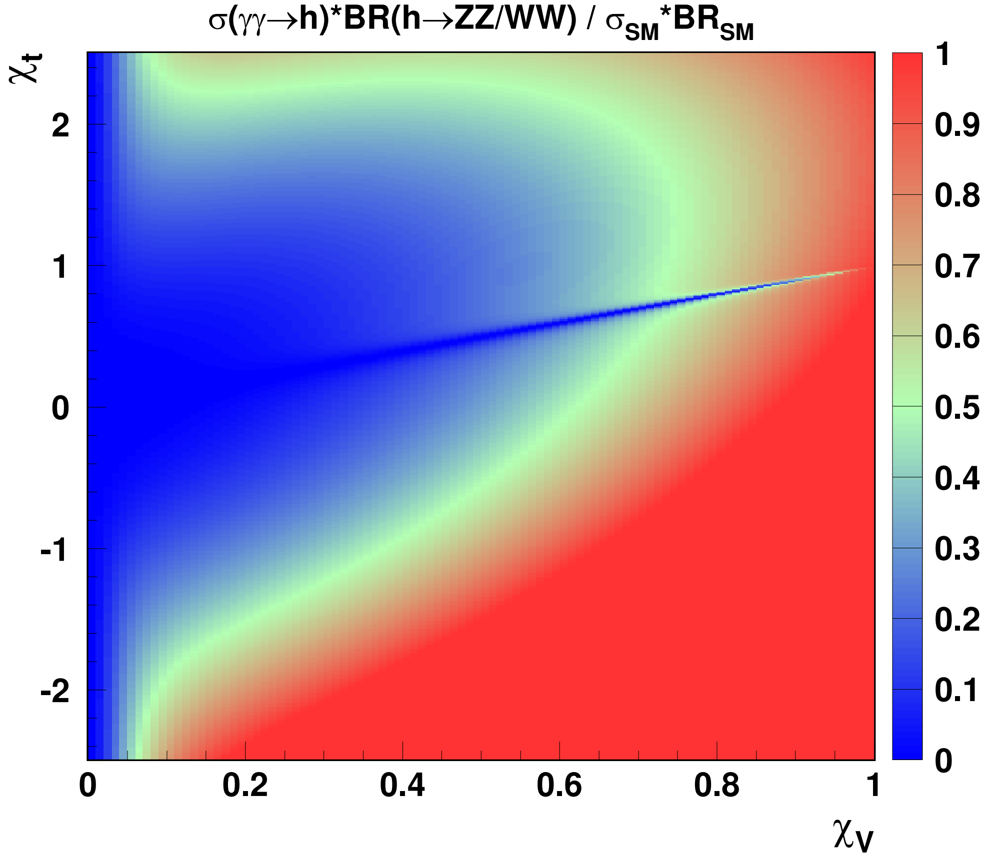
$\sigma(\gamma\gamma \to h) \cdot BR(h \to WW/ZZ)$

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]

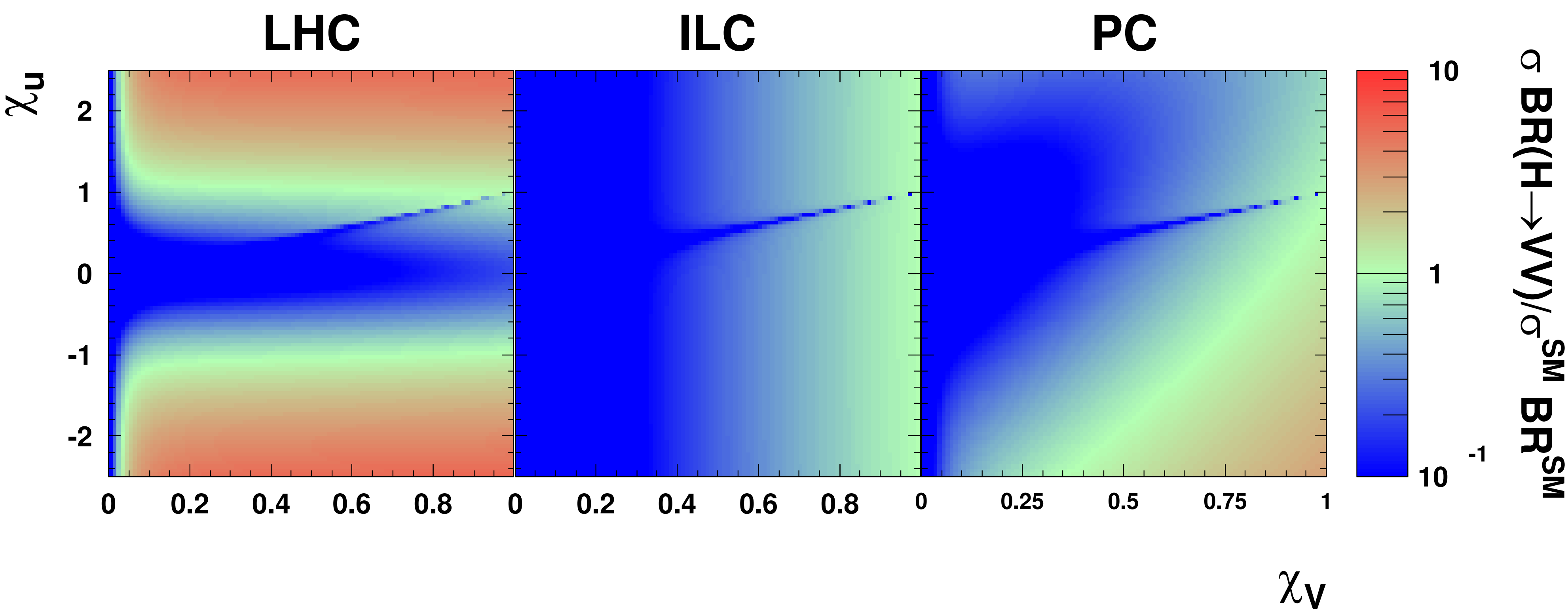
Cross section relative to SM



LHC $\oplus$ ILC $\oplus$ PC

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

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



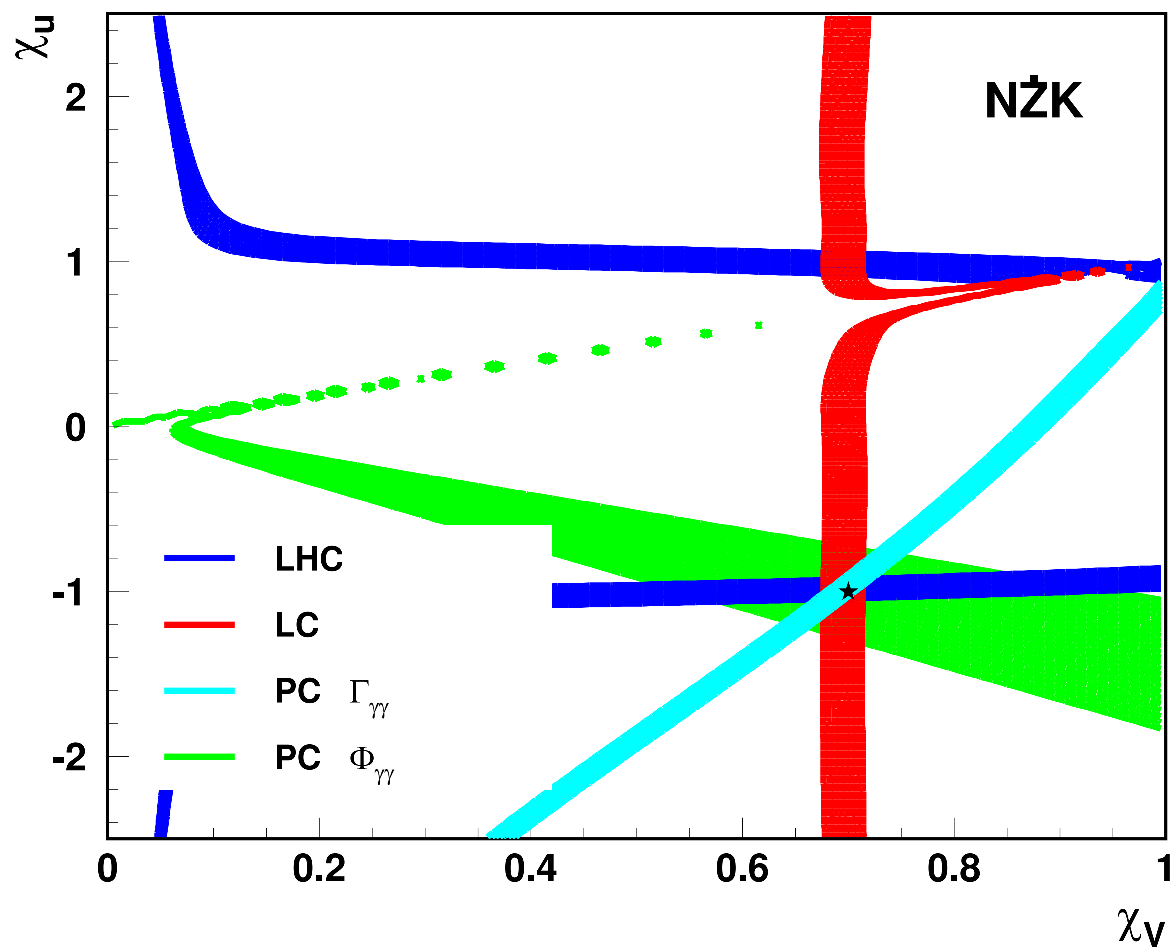
LHC $\oplus$ ILC $\oplus$ PC

Allowed coupling values (1 σ) 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

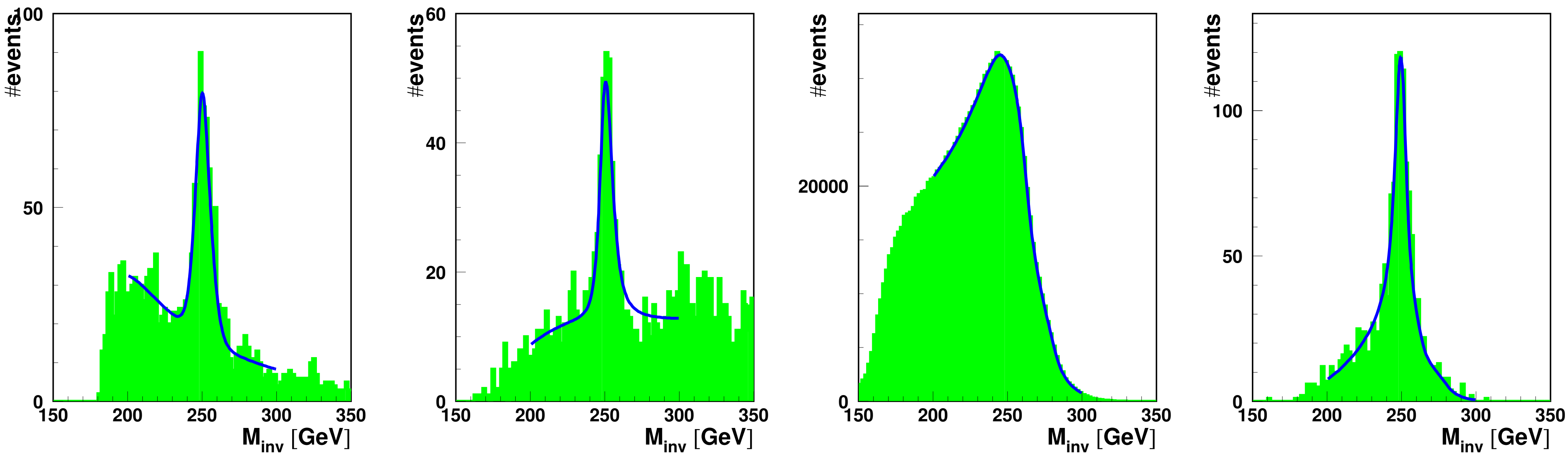
$\chi_V = 0.7 \qquad \chi_u = -1 \qquad M_H = 250$ GeV



LHC $\oplus$ ILC $\oplus$ PC

Combined fit to the expected invariant mass distributions:

LHC ILC PC $H \to WW$ PC $H \to ZZ$



9 parameter fit: • χ_V • χ_u • M_H

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

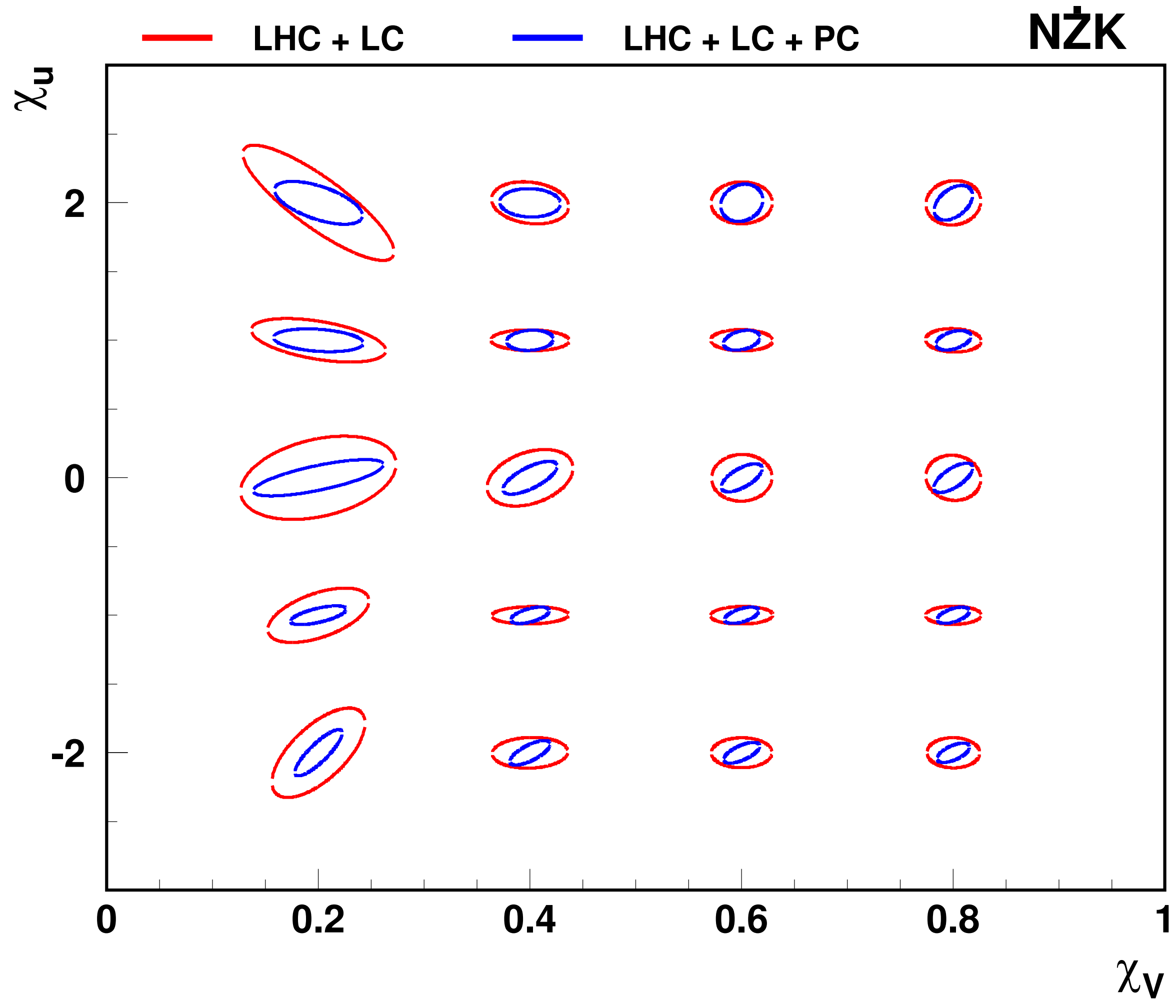
LHC $\oplus$ ILC $\oplus$ PC

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

1σ (stat.+sys.) contours

Comparison of error contours for combined analysis without and with weak PC

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



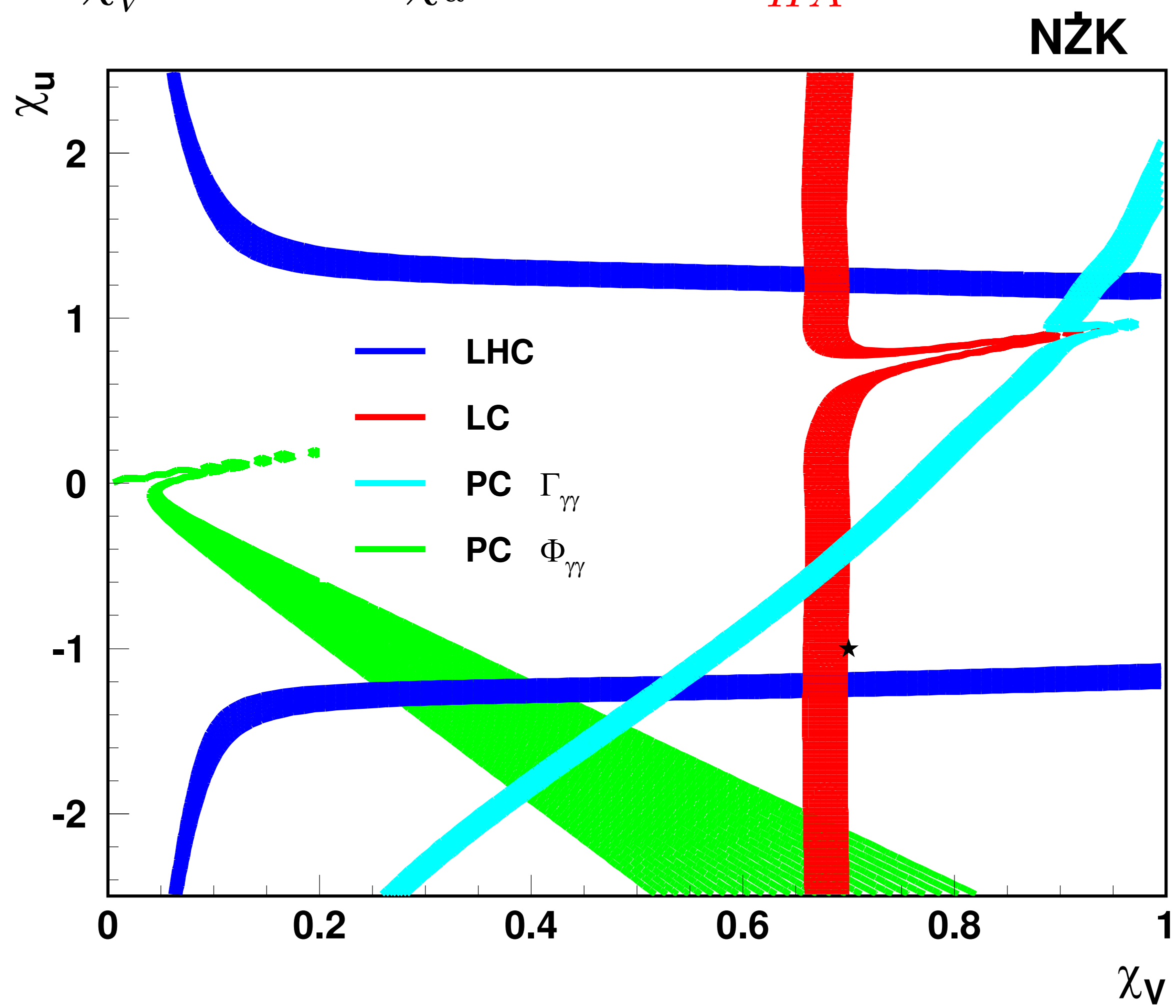
LHC ⊕ ILC ⊕ PC

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 $\Gamma_{\gamma\gamma}$

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



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:

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

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

$\Rightarrow$ 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 violaion)

LHC

Measurement of the production cross section times branching ratio

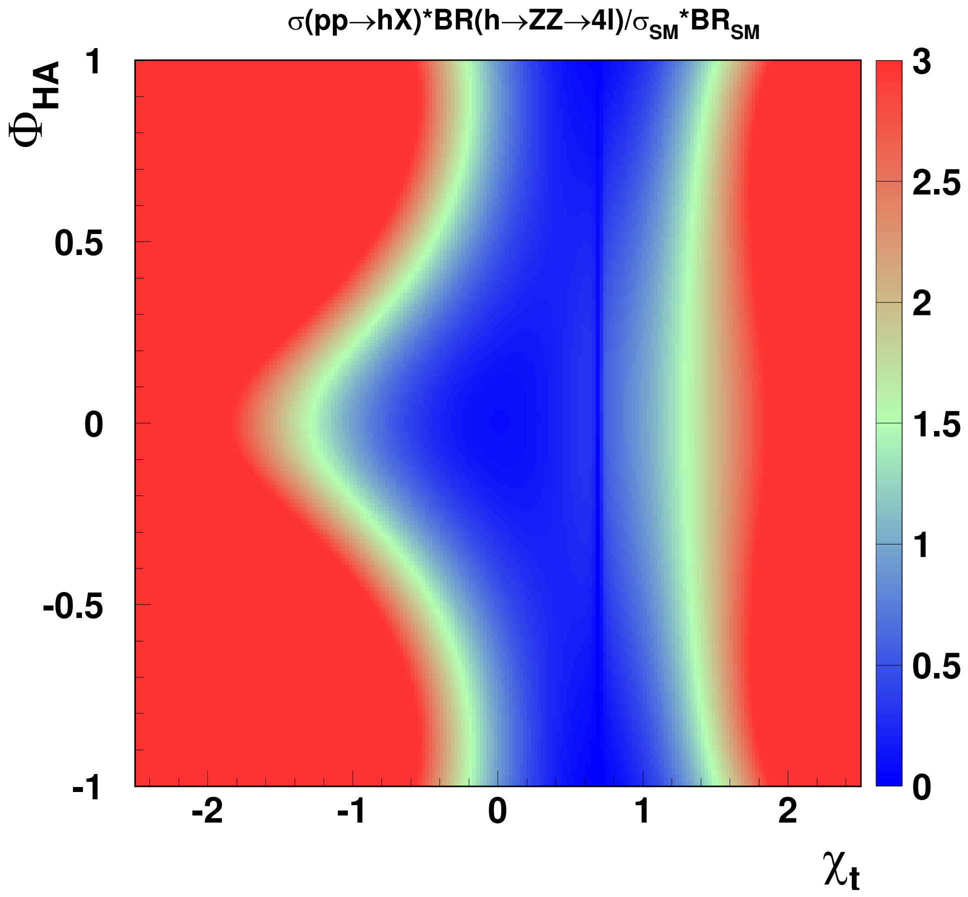
$\sigma(pp \to hX) \cdot BR(h \to ZZ \to 4l)$

not sensitive to χ_V

constrains mainly $|\chi_u|$ value

Limited sensitivity to Φ_{HA}
for $\Phi_{HA} \approx 0$

Cross section relative to SM



ILC

Measurement of the production cross section times branching ratio

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

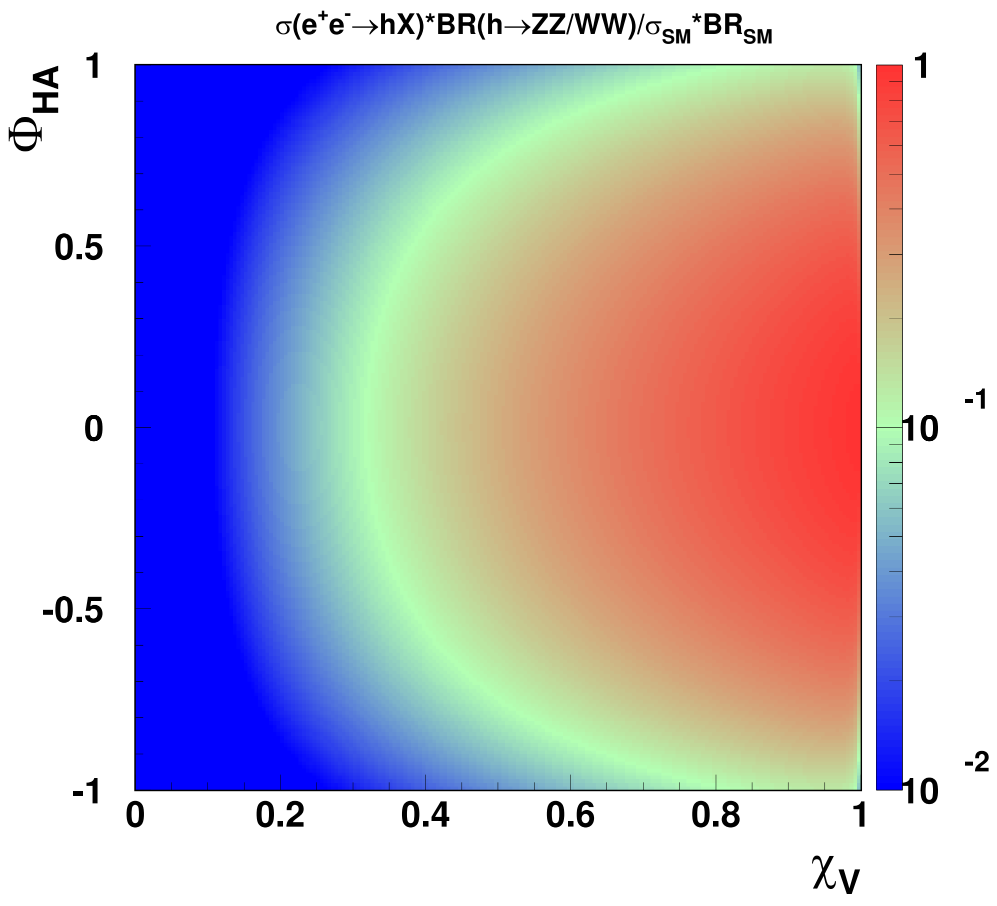
not sensitive to χ_t

constrains mainly χ_V value

Even smaller sensitivity to Φ_{HA}

for $\Phi_{HA} \approx 0$

Cross section relative to SM

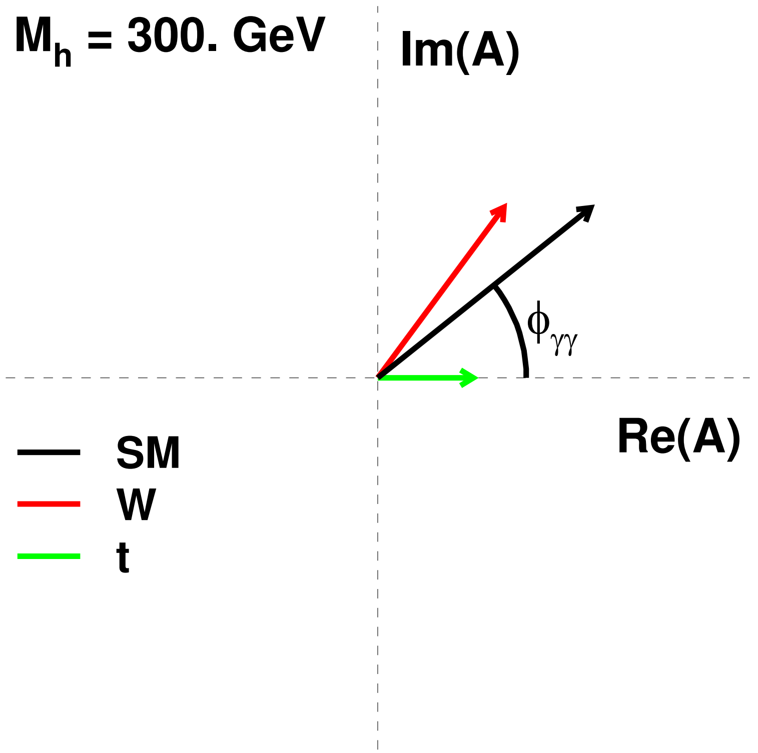


PLC

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

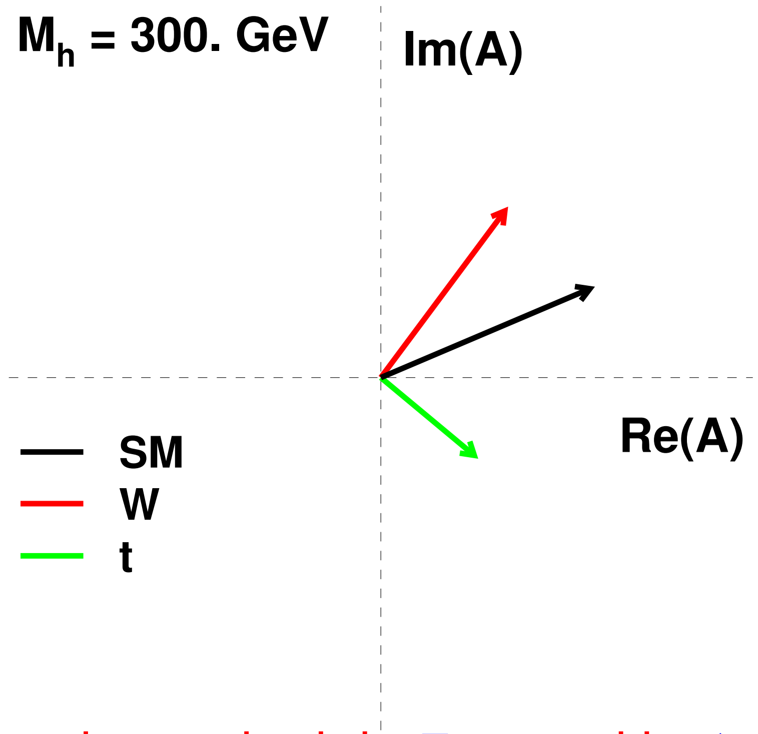
CP-conserving 2HDM (II)

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



2HDM (II) with weak CP violation

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



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

PLC

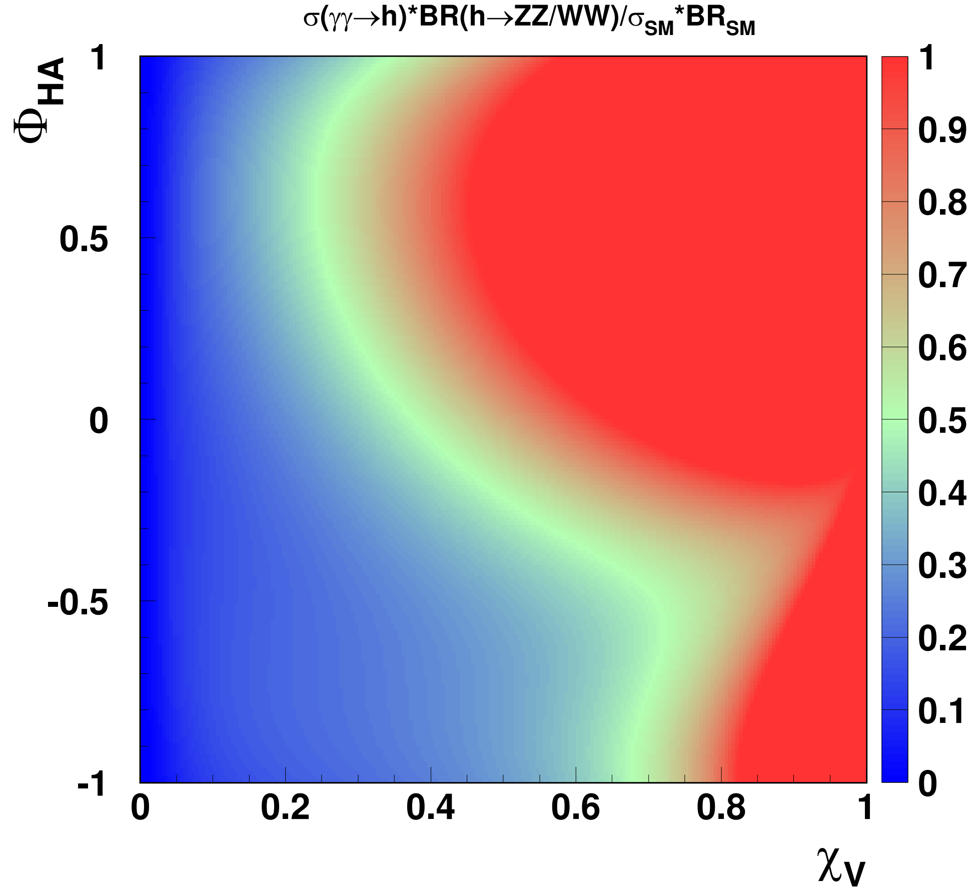
Measurement of the production cross section times branching ratio

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

sensitive to both χ_V and χ_t

also very sensitive to Φ_{HA}

Cross section relative to SM



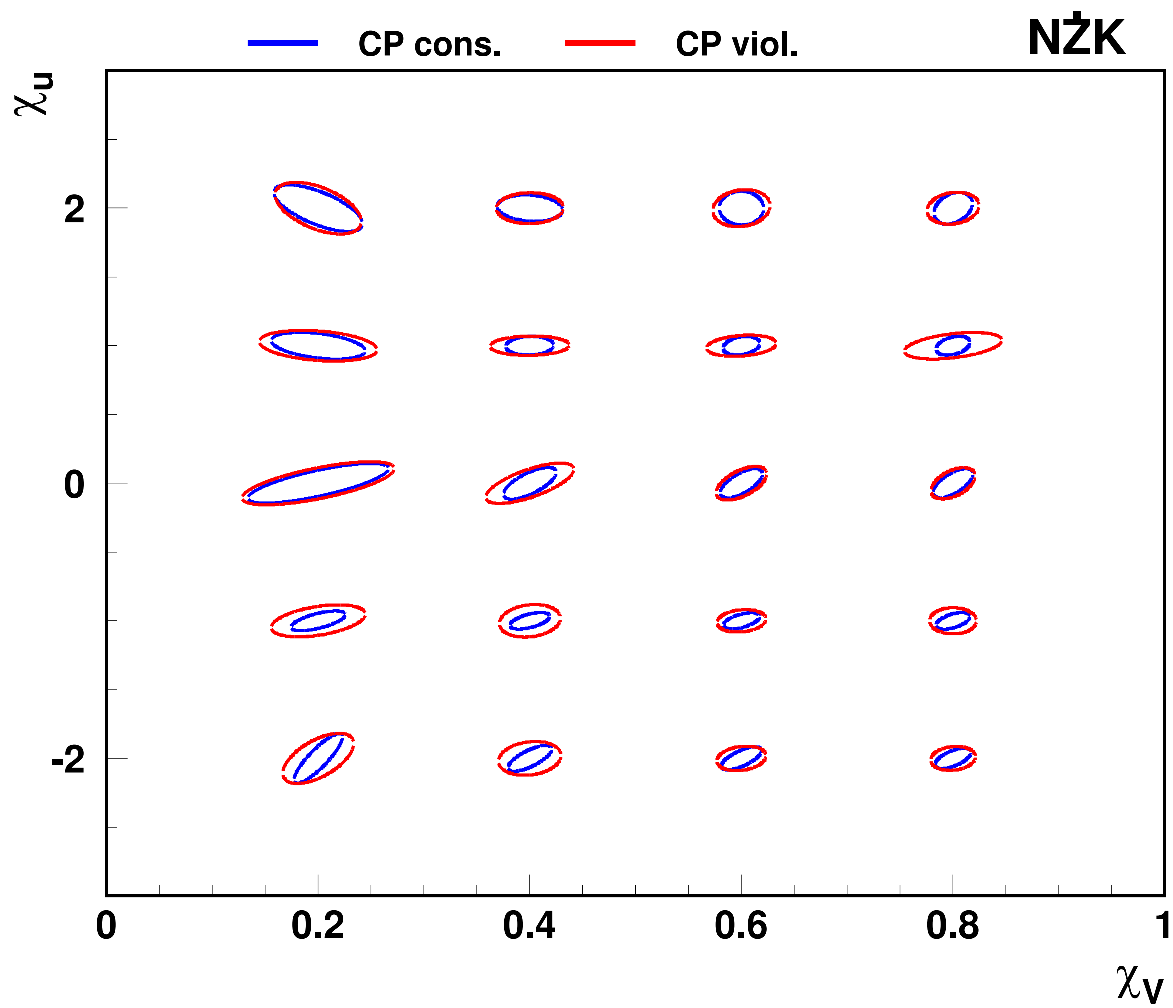
LHC $\oplus$ ILC $\oplus$ PC

Simultaneous fit to LHC, ILC 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



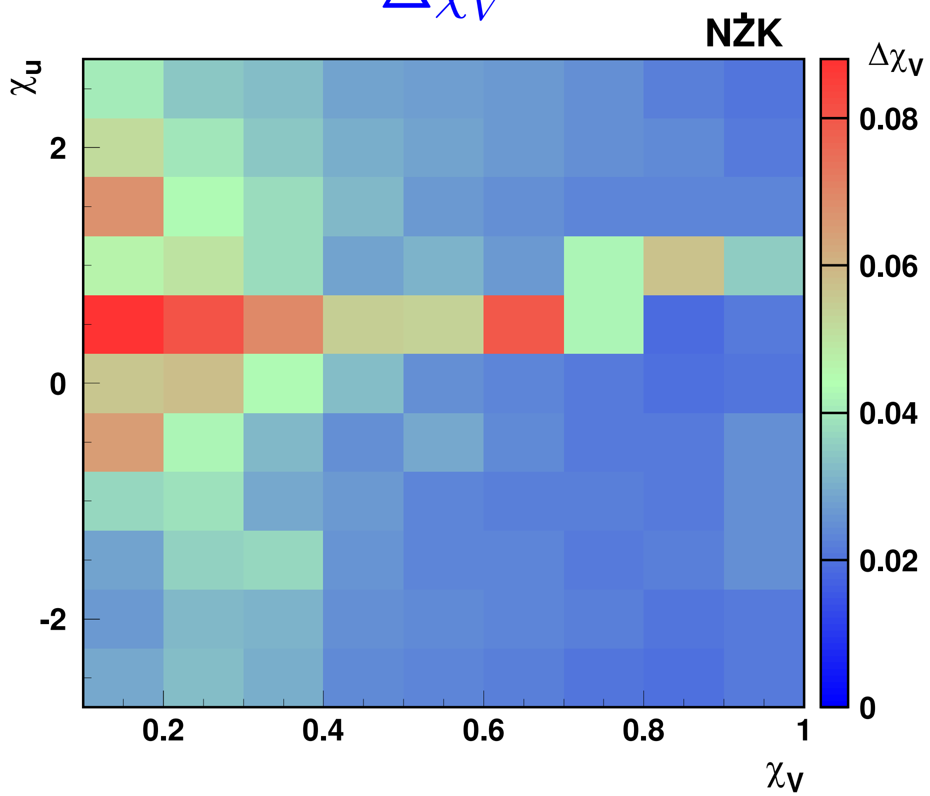
coupling errors $\Rightarrow$ next slide

LHC $\oplus$ ILC $\oplus$ PC

Coupling errors

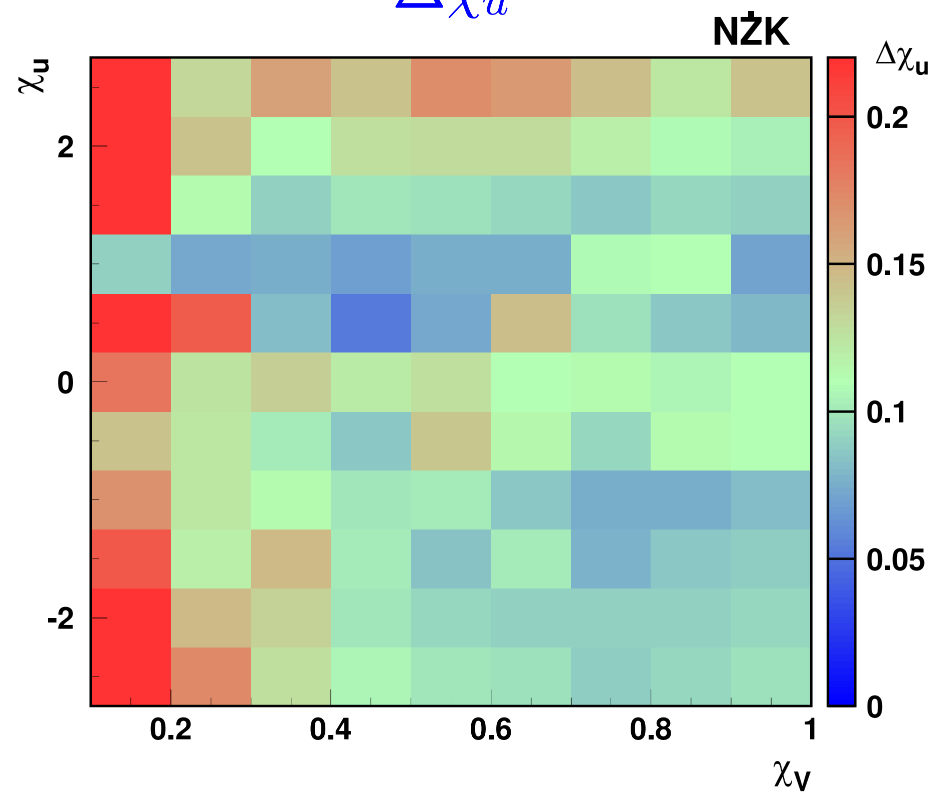
Estimated total errors on Higgs boson couplings for M_H=250 GeV

$\Delta\chi_V$



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

$\Delta\chi_u$



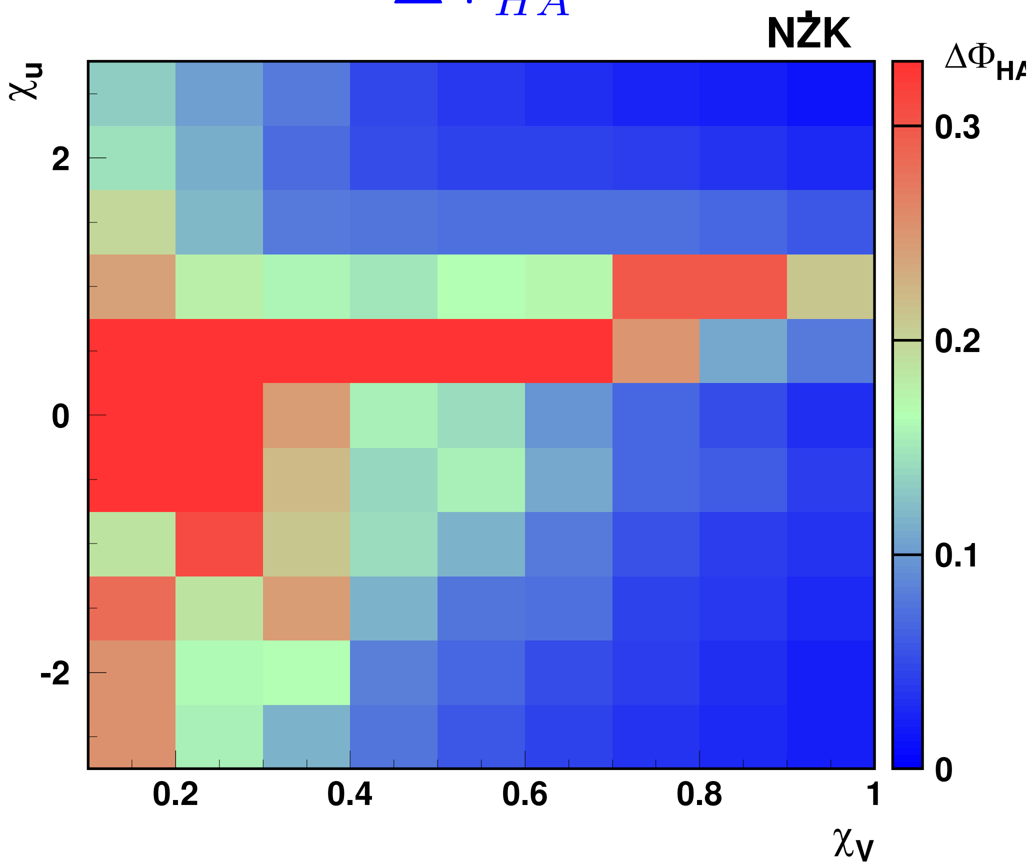
$\langle\Delta\chi_u\rangle$ = 0.12

LHC $\oplus$ ILC $\oplus$ 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

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

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

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.

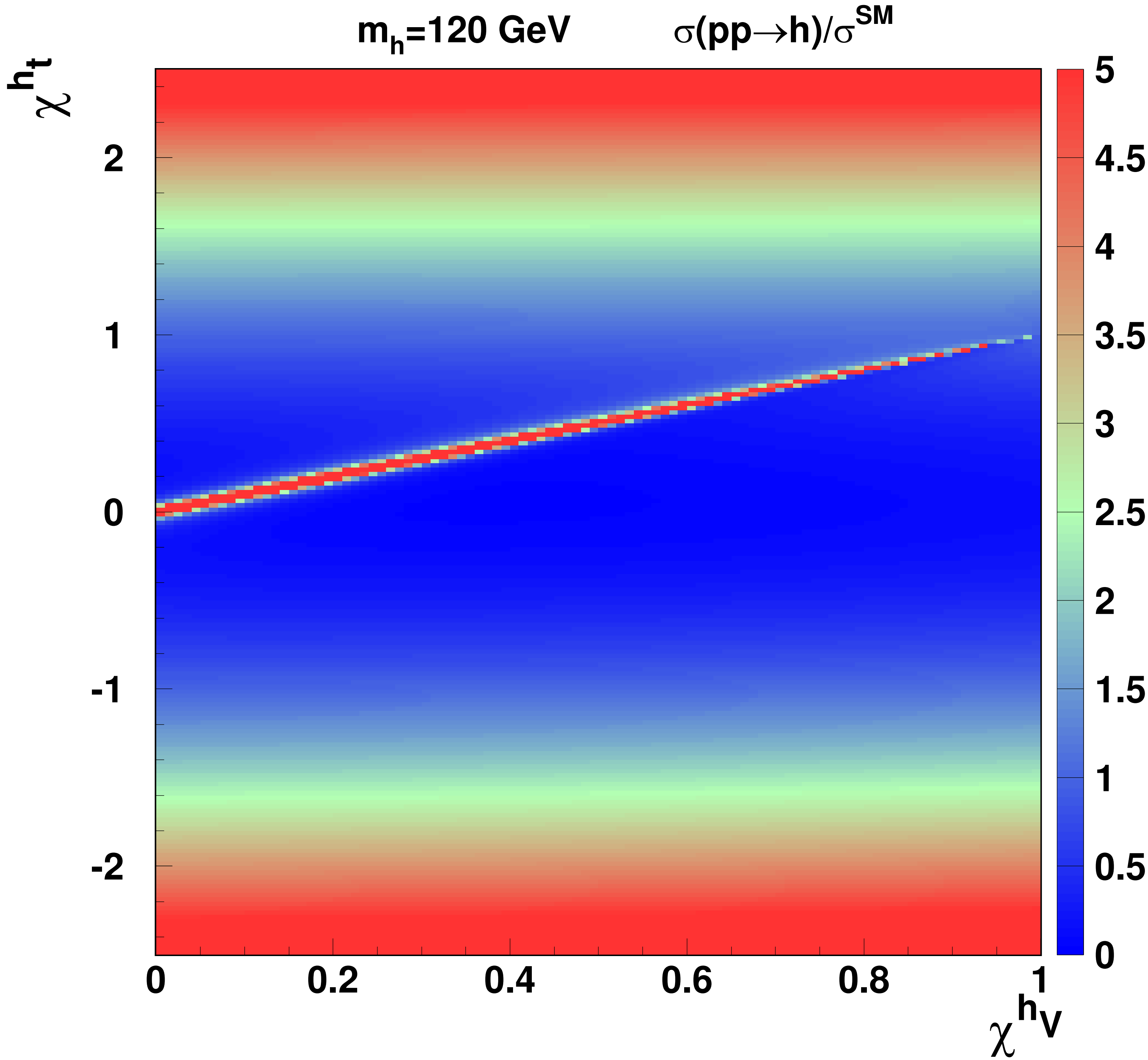
Only the combined analysis of LHC, ILC and PC measurements
allows for the determination of the CP-violating $H - A$ mixing angle Φ_{HA}.

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

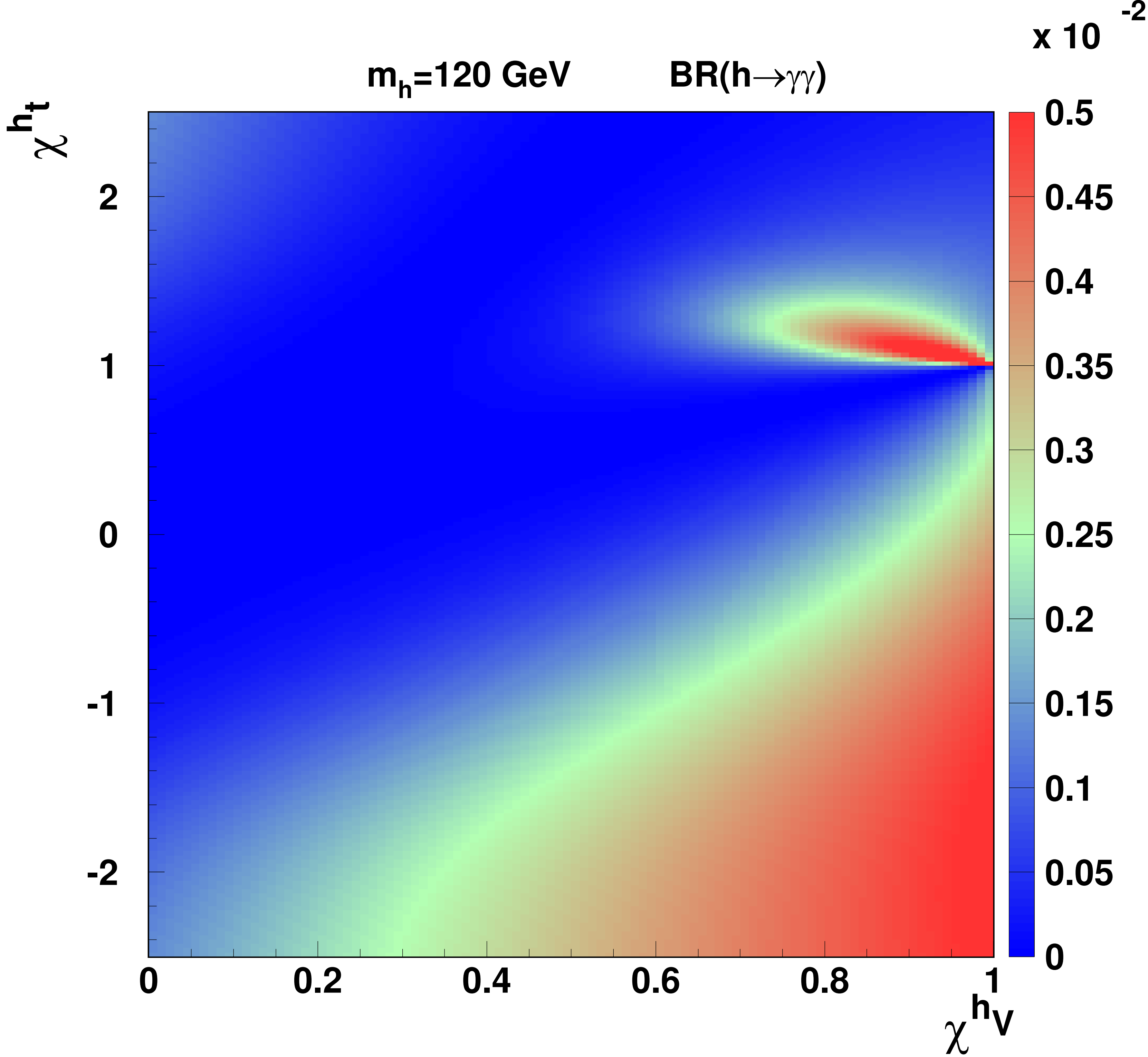
Systematic uncertainties

LHC $\oplus$ ILC $\oplus$ PC analysis

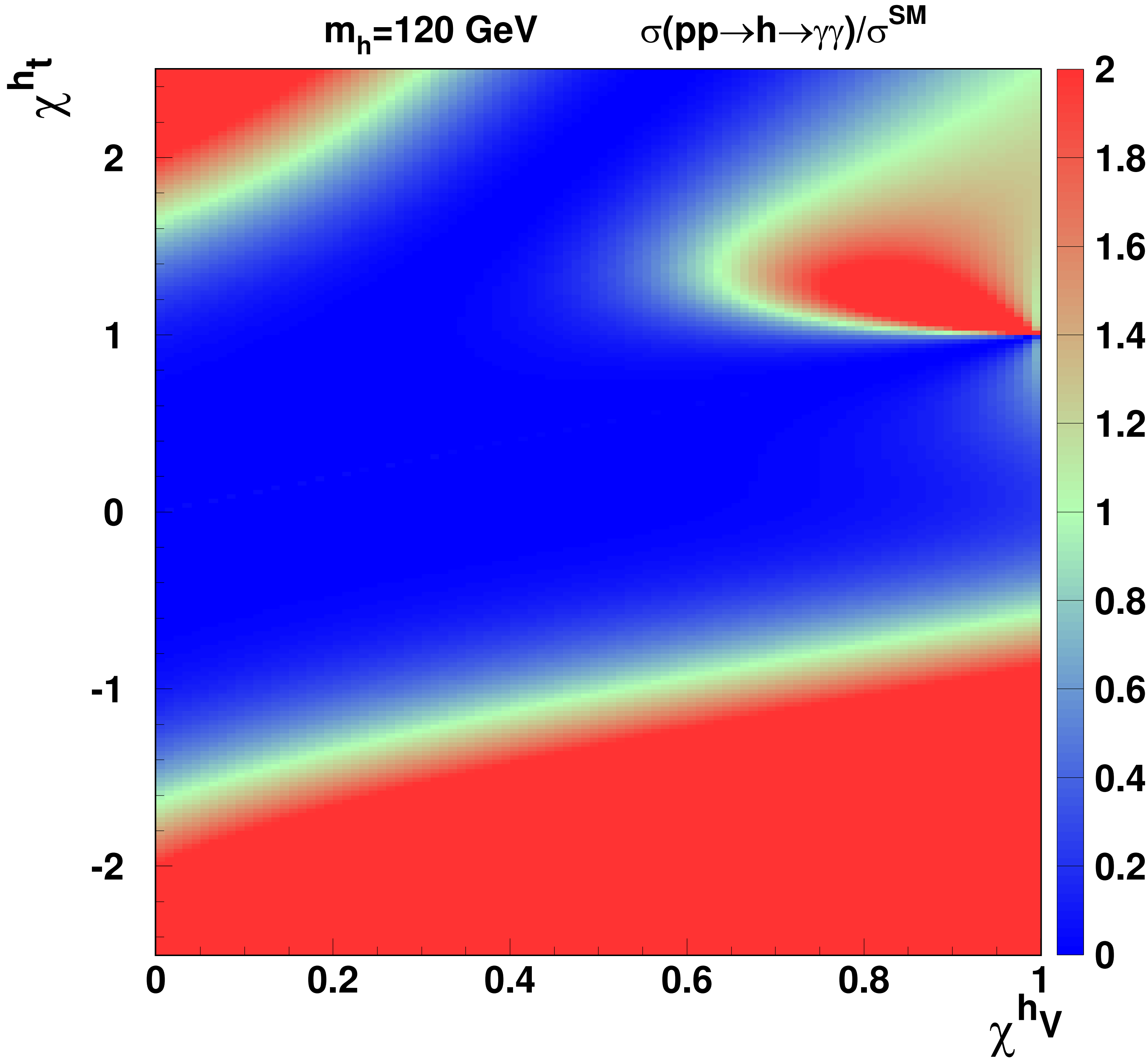
Parameter:	Assumed uncertainty:
• Higgs boson mass	$\Rightarrow$ unconstrained
• $\gamma\gamma$ luminosity	$\Rightarrow$ unconstrained
• $\gamma\gamma$ spectra shape parameters	$\Rightarrow$ 5% uncertainty
• background normalization for e^+e^-	$\Rightarrow$ 5% uncertainty
• signal normalization for pp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



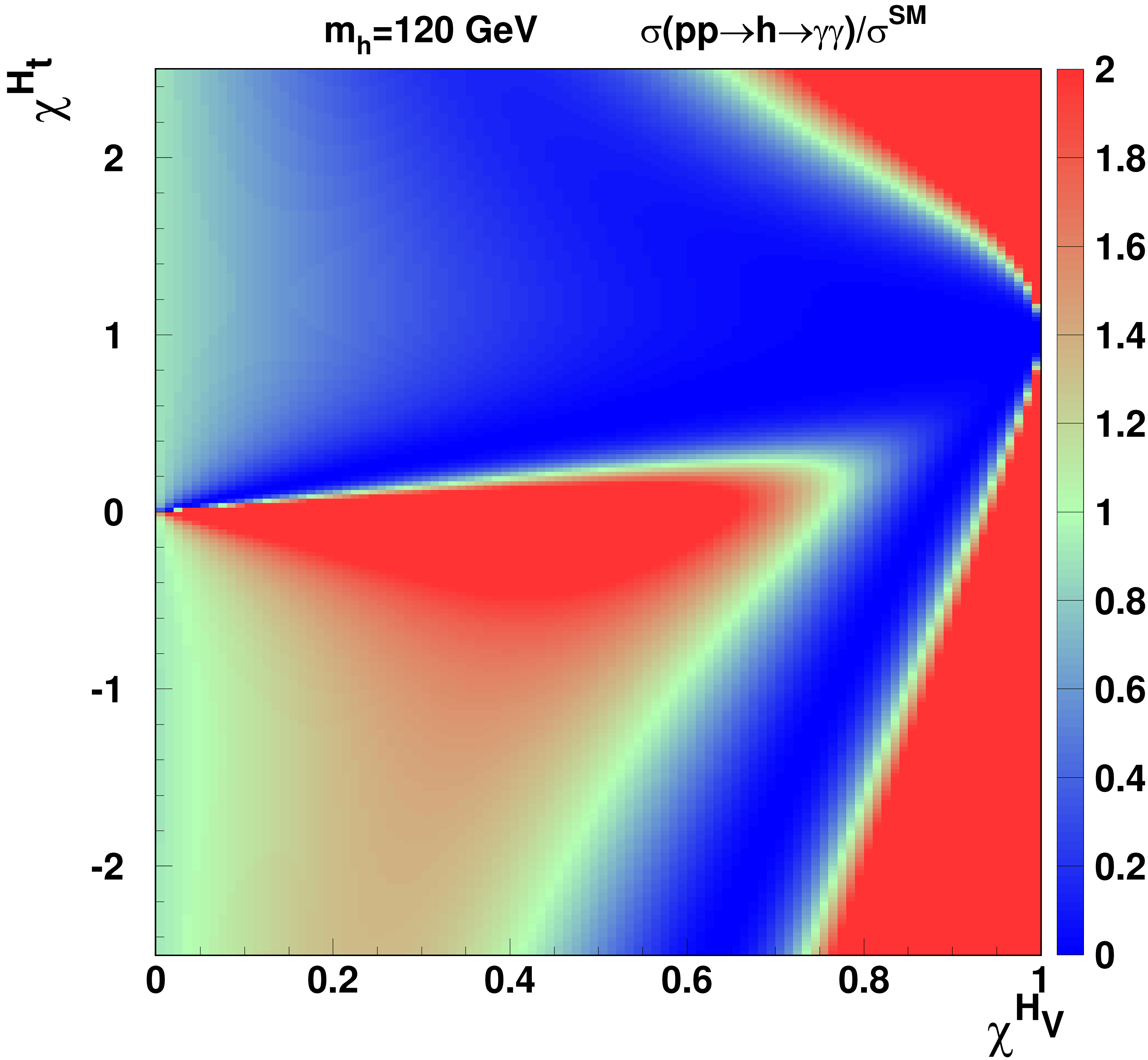
m_h=120 GeV
$\sigma(pp\to h)/\sigma^{SM}$
χ^{h_t}
χ^{h_V}
2
1
0
-1
-2
0
0.2
0.4
0.6
0.8
1
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0



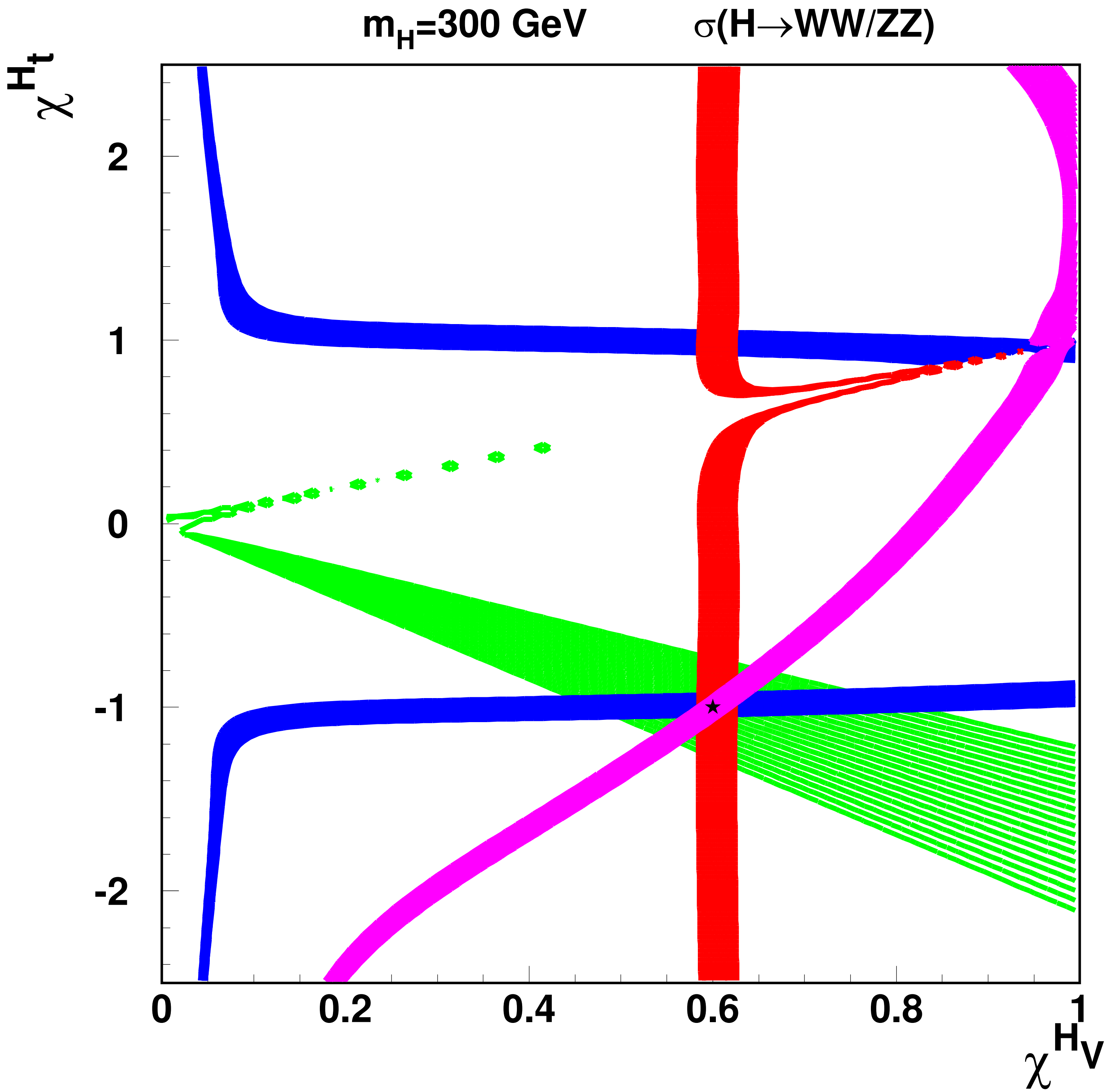
x 10^-2
m_h=120 GeV
BR(h→γγ)
χ^h_t
2
1
0
-1
-2
0
0.2
0.4
0.6
0.8
1
χ^h_V
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0



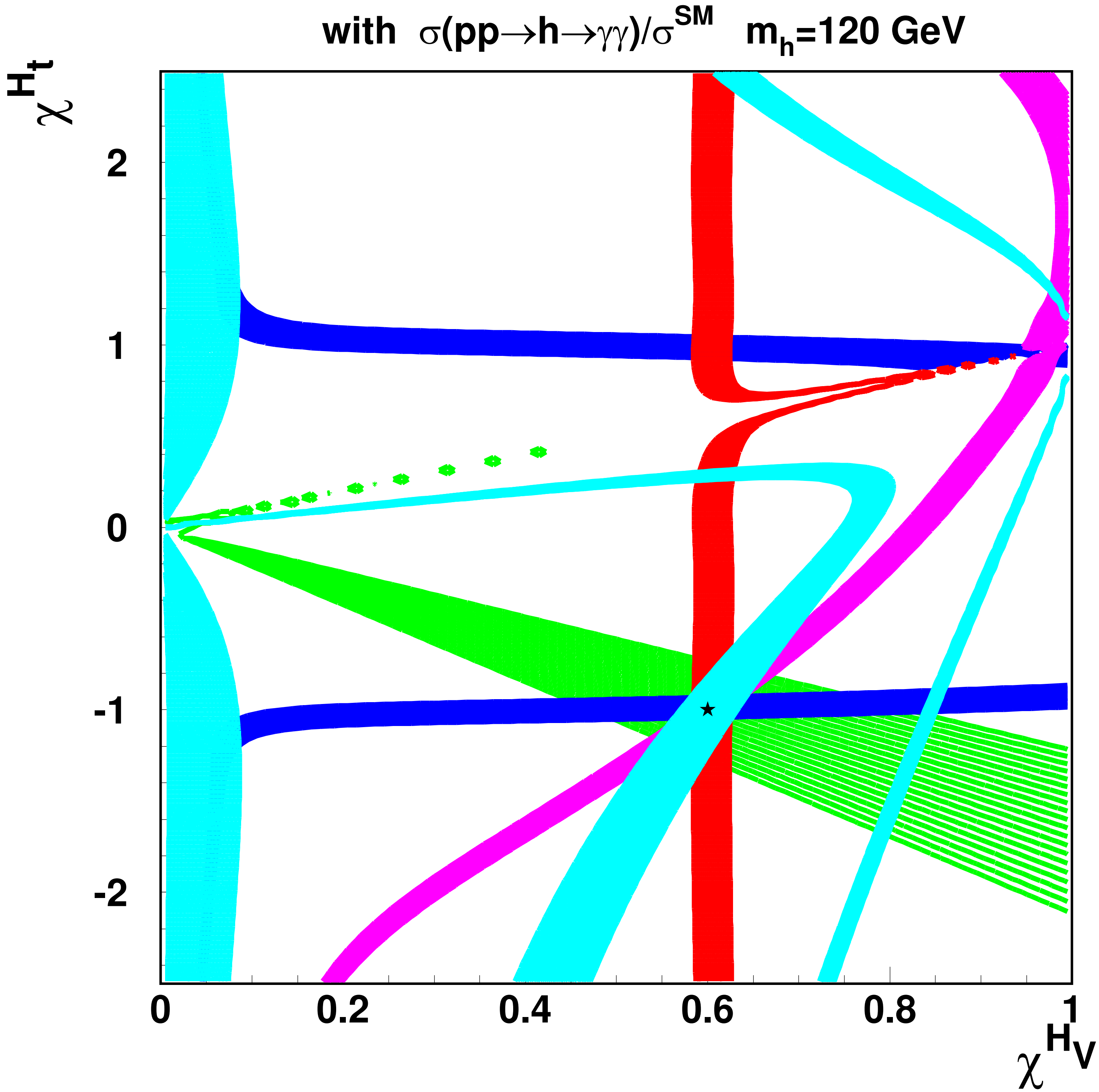
m_h=120 GeV
$\sigma(pp\to h\to\gamma\gamma)/\sigma^{SM}$
χ^{h_t}
χ^{h_V}
2
1
0
-1
-2
0
0.2
0.4
0.6
0.8
1
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0



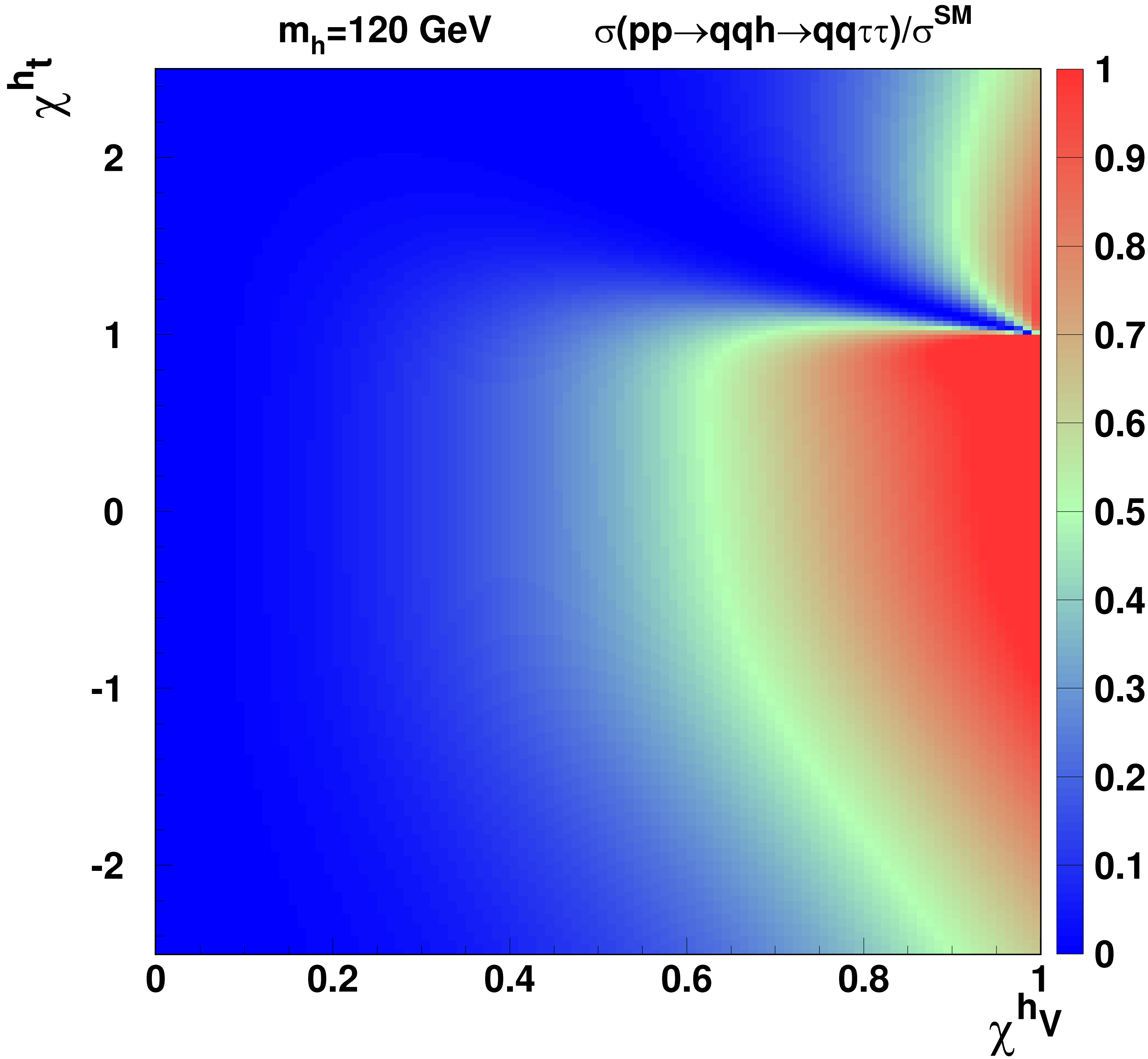
m_h=120 GeV
$\sigma(pp\to h\to\gamma\gamma)/\sigma^{SM}$
χ^{H_t}
χ^{H_V}
2
1
0
-1
-2
0
0.2
0.4
0.6
0.8
1
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0



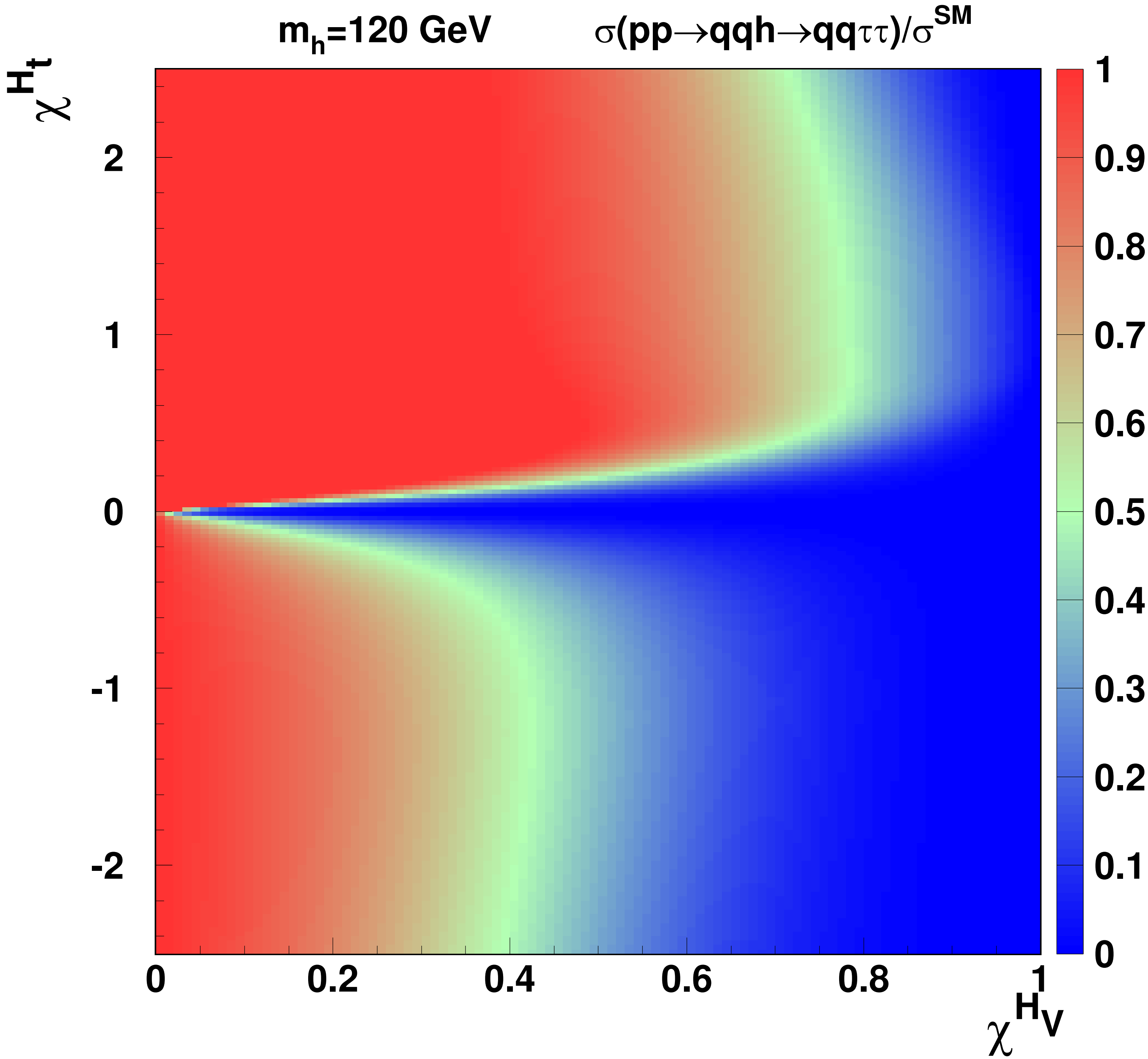
m_H=300 GeV
σ(H→WW/ZZ)
χ^H_t
2
1
0
-1
-2
0
0.2
0.4
0.6
0.8
1
χ^H_V



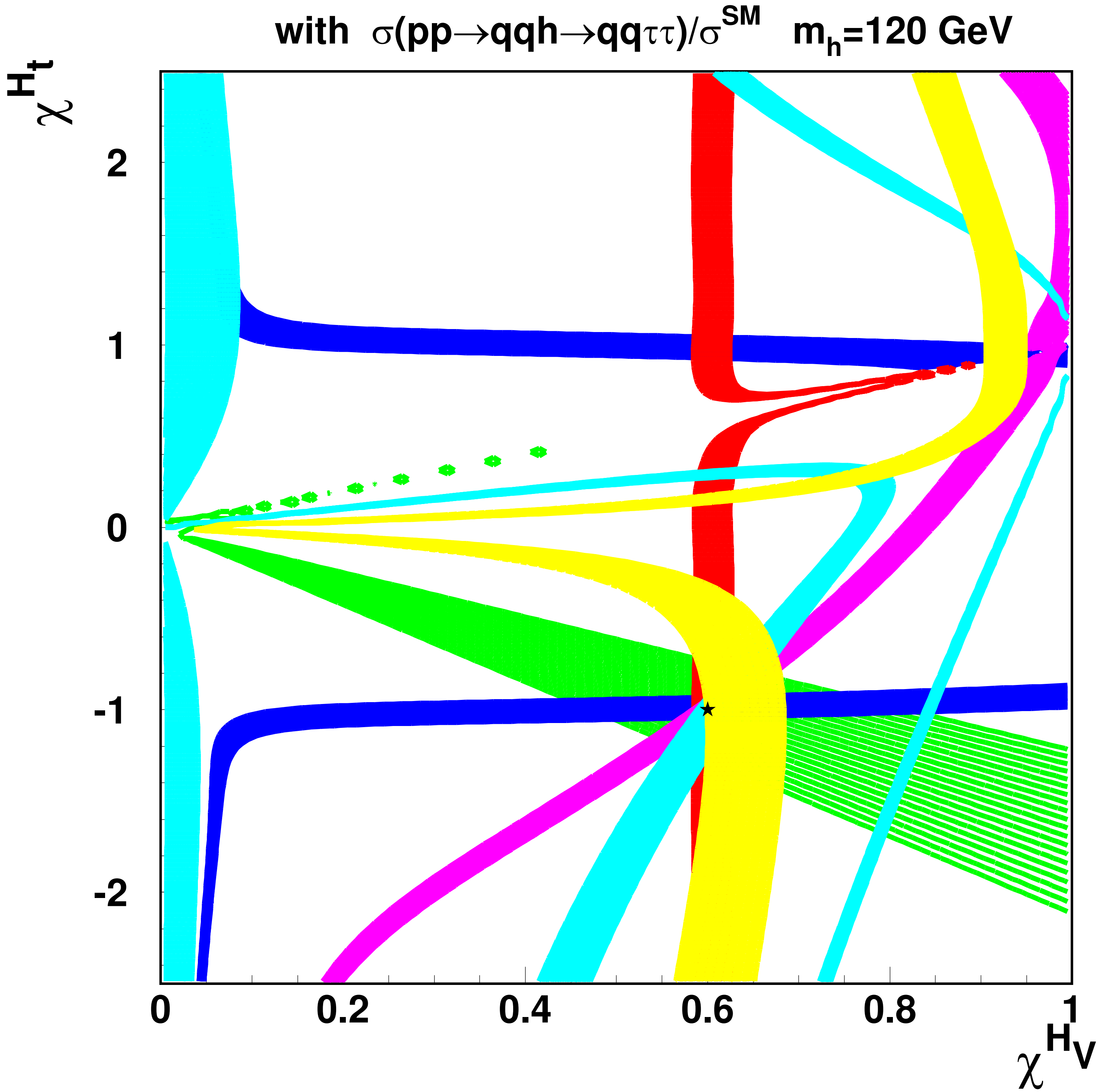
with σ(pp→h→γγ)/σ^SM m_h=120 GeV
χ^Ht
2
1
0
-1
-2
0
0.2
0.4
0.6
0.8
1
χ^HV

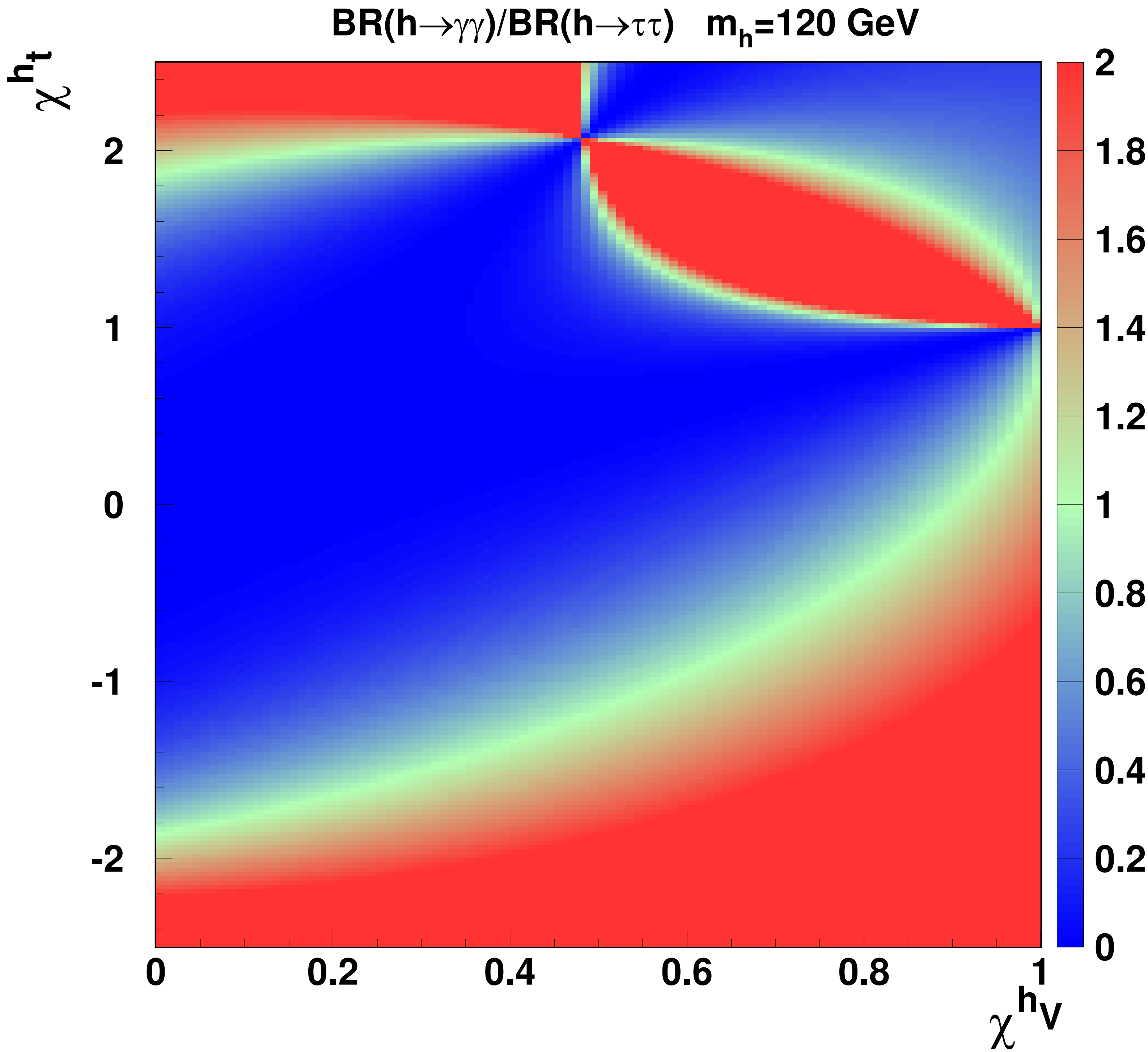


m_h=120 GeV
σ(pp→qqh→qqττ)/σ^SM
χ^h_t
χ^h_V
2
1
0
-1
-2
0
0.2
0.4
0.6
0.8
1
0.9
0.7
0.5
0.3
0.1

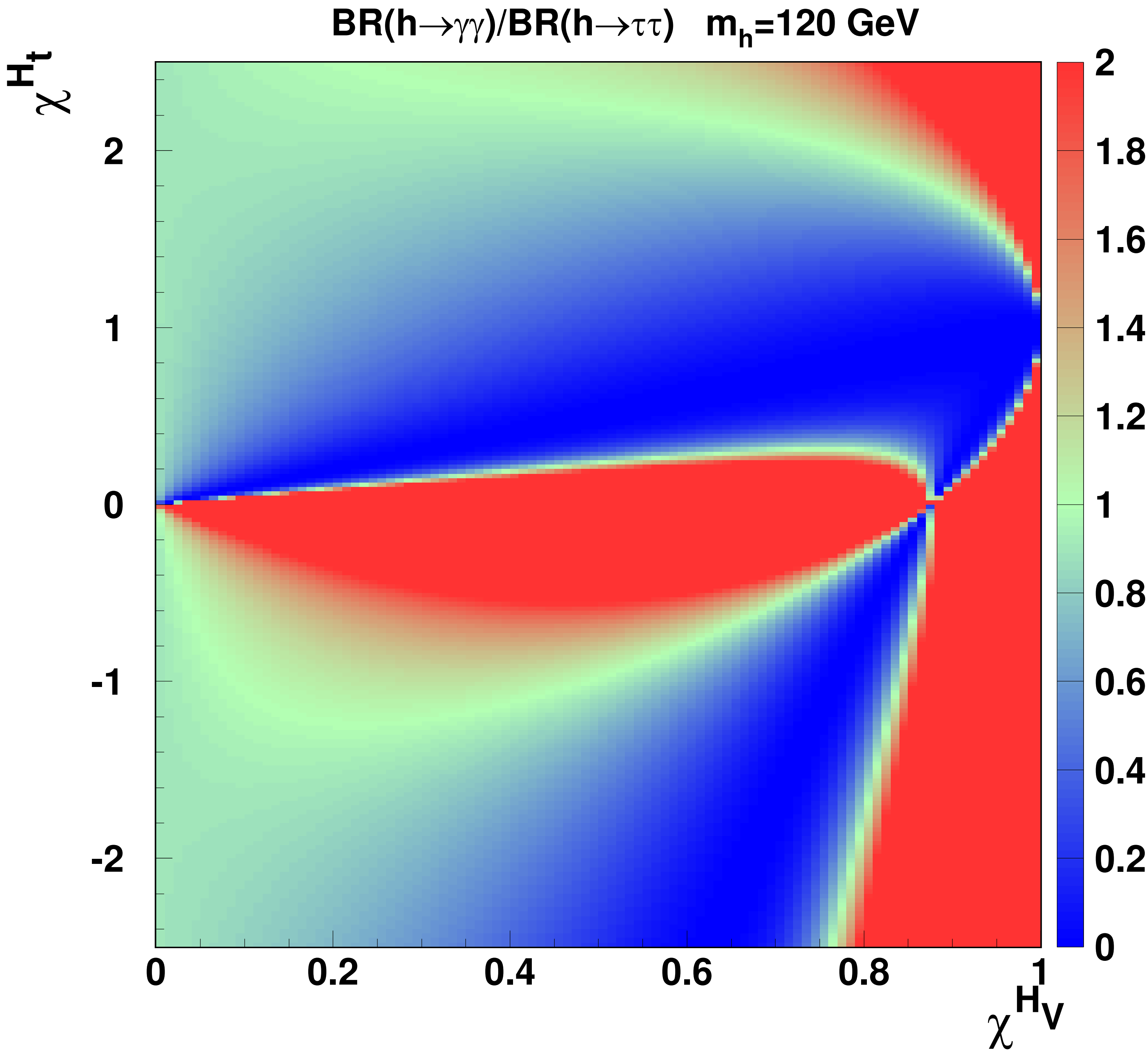


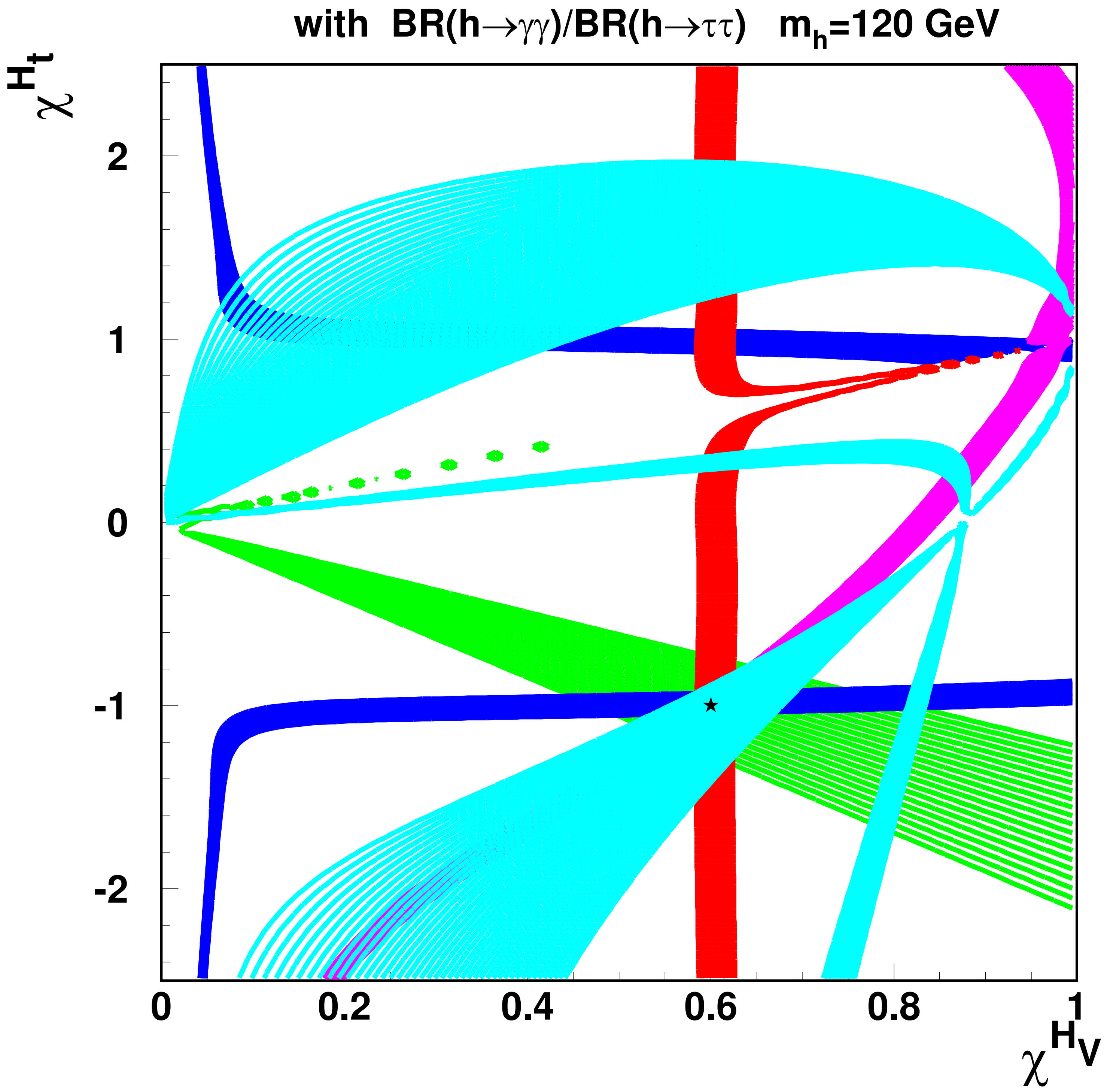
m_h=120 GeV
$\sigma(pp\to qqh\to qq\tau\tau)/\sigma^{SM}$
χ^{H_t}
2
1
0
-1
-2
0
0.2
0.4
0.6
0.8
1
χ^{H_V}
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0


with σ(pp→qqh→qqττ)/σ^SM m_h=120 GeV
χ^{H_t}
2
1
0
-1
-2
0
0.2
0.4
0.6
0.8
1
χ^{H_V}

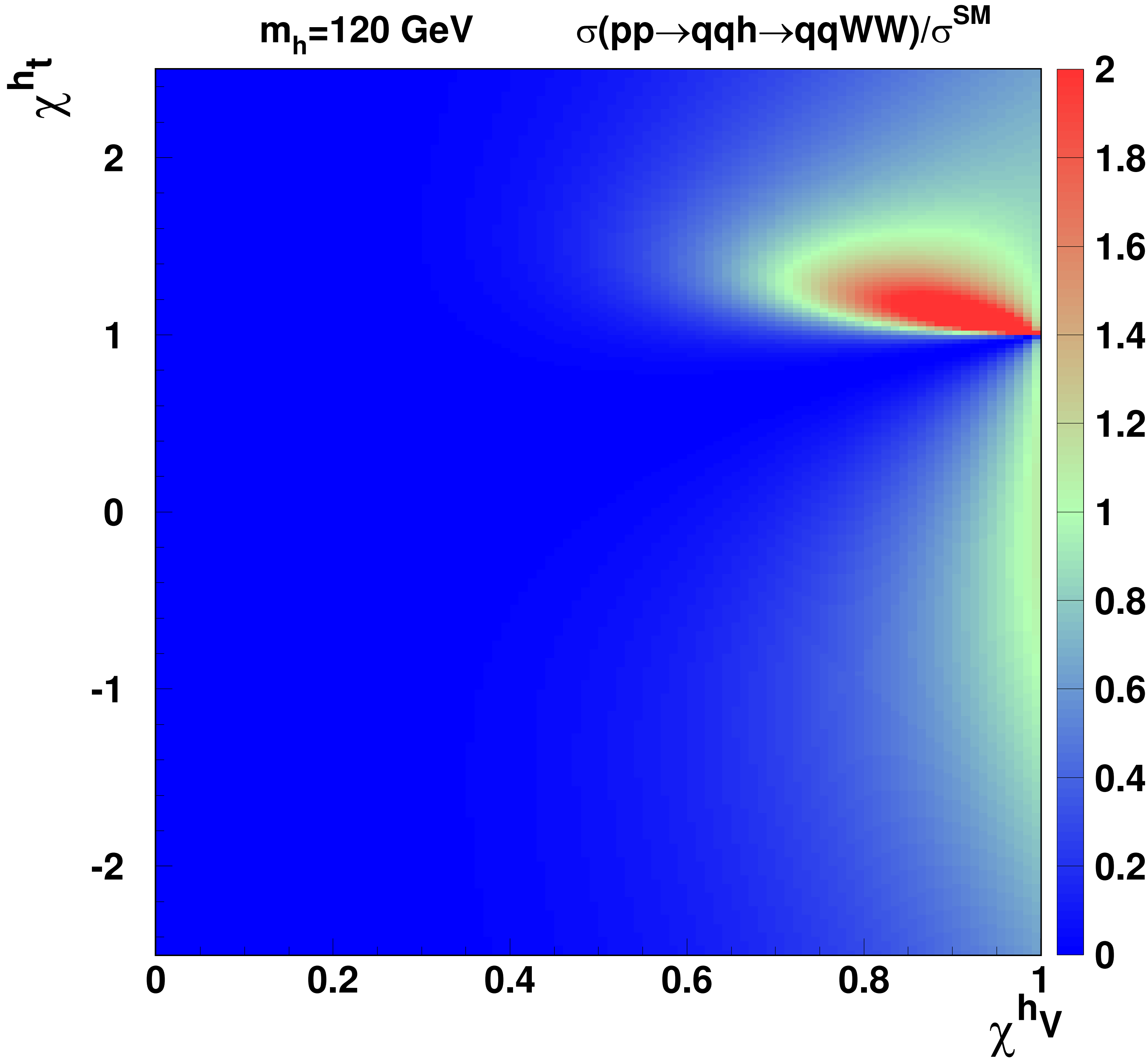


BR(h→γγ)/BR(h→ττ) m_h=120 GeV
χ^{h_t}
χ^{h_V}
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-1
-2
0.2
0.4
0.6
0.8

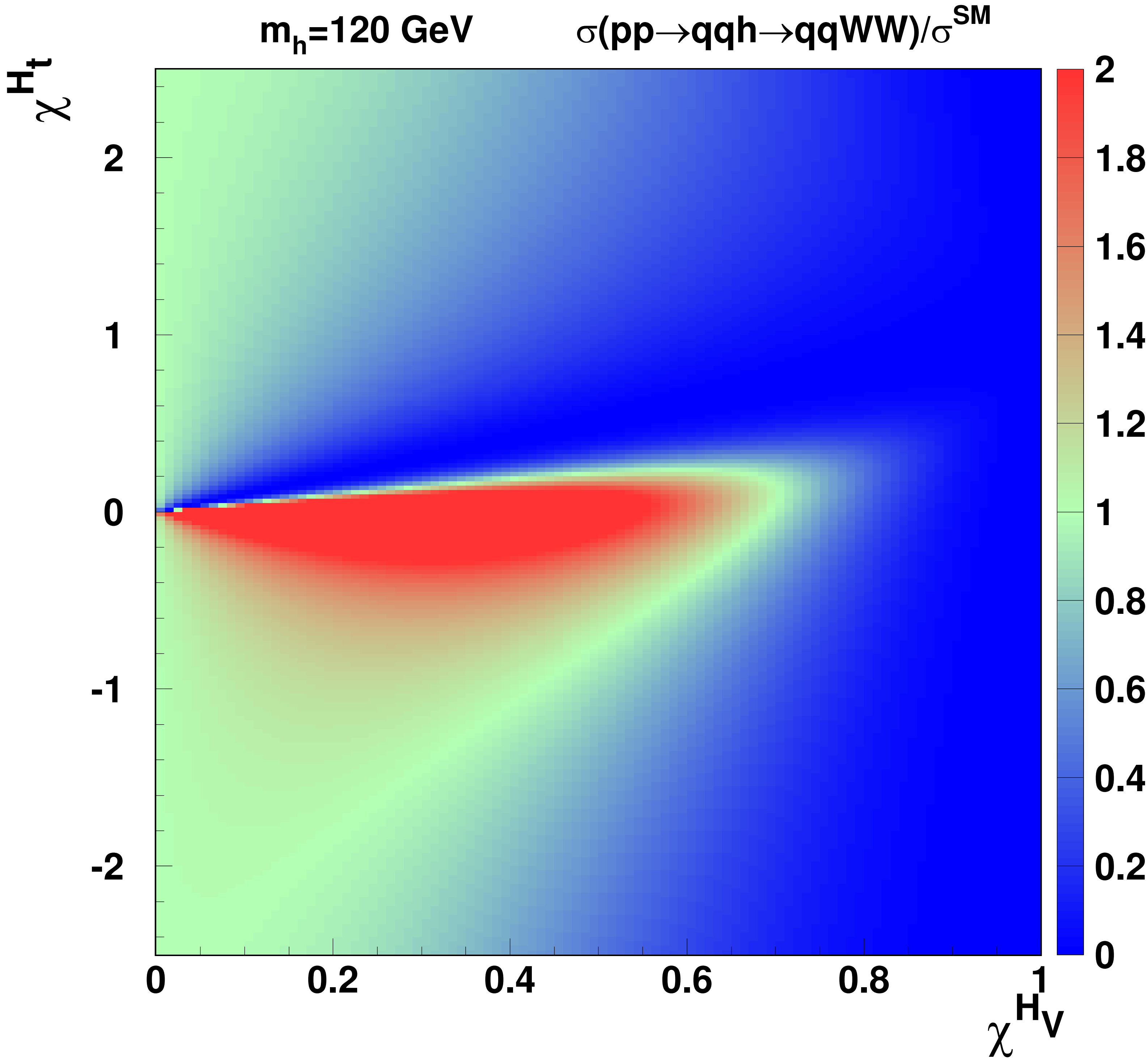

BR(h→γγ)/BR(h→ττ) m_h=120 GeV
χ^{H_t}
χ^{H_V}
2
1
0
-1
-2
0
0.2
0.4
0.6
0.8
1
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0



with BR(h→γγ)/BR(h→ττ) m_h=120 GeV
χ^Ht
2
1
0
-1
-2
0
0.2
0.4
0.6
0.8
1
χ^HV



m_h=120 GeV
$\sigma(pp\to qqh\to qqWW)/\sigma^{SM}$
χ^{h_t}
χ^{h_V}
2
1
0
-1
-2
0
0.2
0.4
0.6
0.8
1
1.8
1.6
1.4
1.2



m_h=120 GeV
σ(pp→qqh→qqWW)/σ^SM
χ^Ht
2
1
0
-1
-2
0
0.2
0.4
0.6
0.8
1
χ^HV
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0