Two-photon width and phase measurement from the Higgs decays into WW and ZZ

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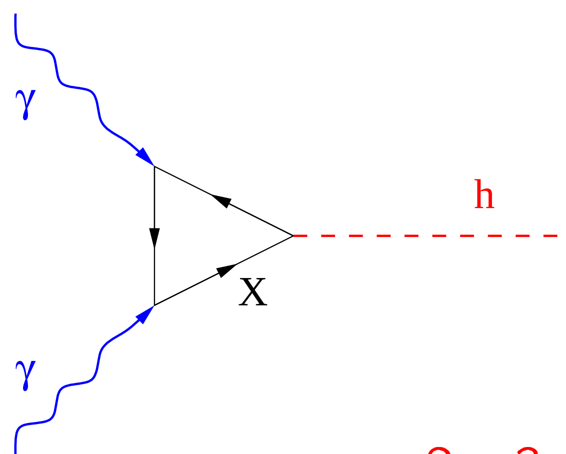
Outline

- $\gamma\gamma \to h$: two-photon width and phase
  - expected effects of new particles
- $\gamma\gamma \to W^+W^-$, ZZ: Higgs signal
  - SM background and interference effects
- Analysis
  - simulation, event selection, parametrization
- SM Higgs results
  - measurement of $\Gamma_{\gamma\gamma}$ and $\phi_{\gamma\gamma}$
- 2HDM(II) Higgs results
  - SM-like scenario B

$\gamma\gamma \to h$

Width

Two-photon width of the Higgs boson $\Gamma_{\gamma\gamma}$ is sensitive to all massive and charged particles in the loop:



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

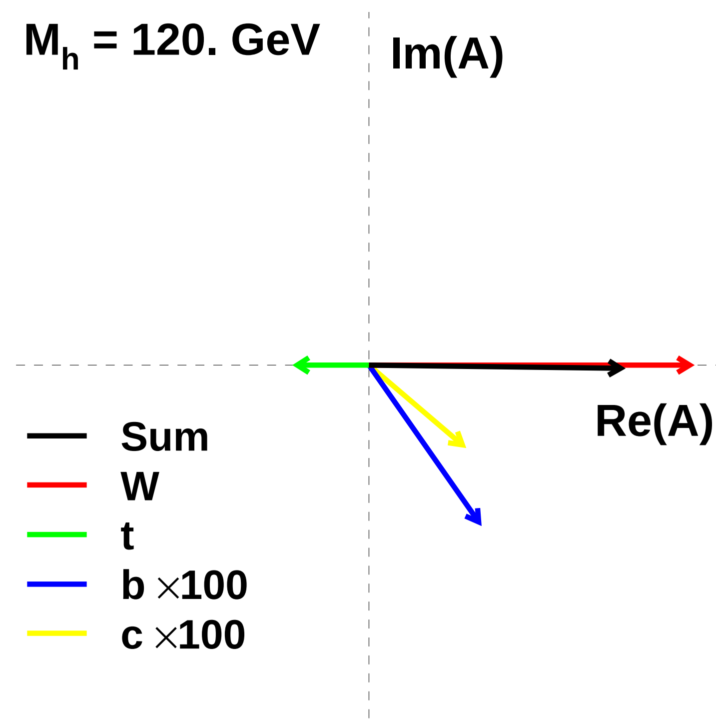
where:

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

two-photon amplitude

Amplitude

For Higgs boson mass $M_h < 2\,M_W$ amplitude $\mathcal{A}$ is real



contribution to $Im(\mathcal{A})$ from light fermions - very tiny

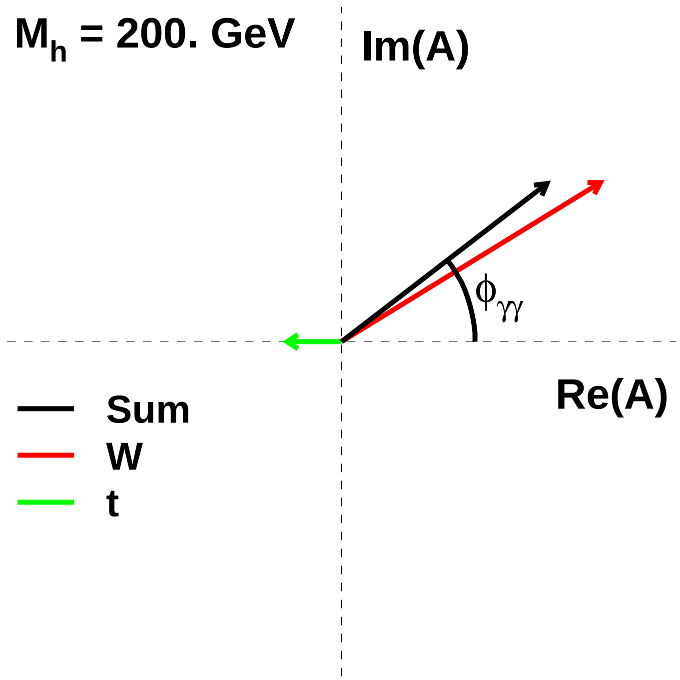
contribution from new heavy particles - real

$\gamma\gamma \to h$

Phase

However, for $M_h > 2\ M_W$

W contribution is complex



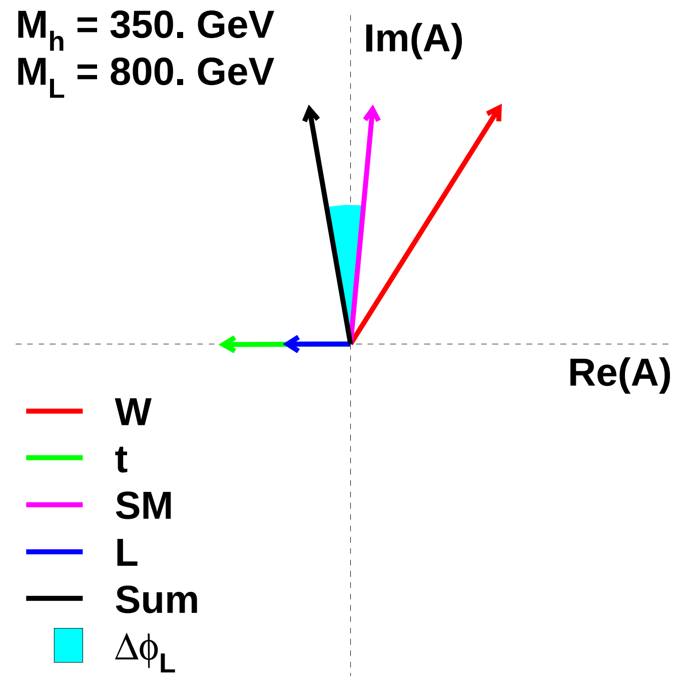
$\Rightarrow\ \mathcal{A} = |\mathcal{A}| \cdot e^{i\phi}$ phase $\phi_{\gamma\gamma} \neq 0$

$$\Gamma_{\gamma\gamma} \sim |\mathcal{A}|^2 = Im(\mathcal{A})^2 + Re(\mathcal{A})^2$$

New particles

Will contribute to both $\Gamma_{\gamma\gamma}$ and $\phi_{\gamma\gamma}$.

For new charged lepton:



for M_h ~350 GeV

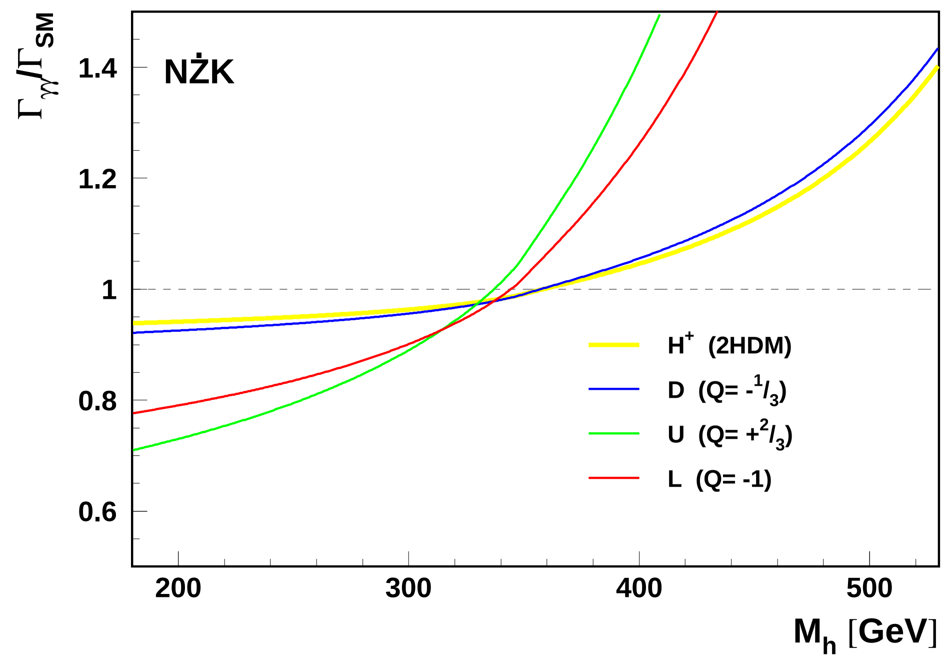
$\Rightarrow$ amplitude mostly imaginary: $Re(\mathcal{A}) \sim 0$

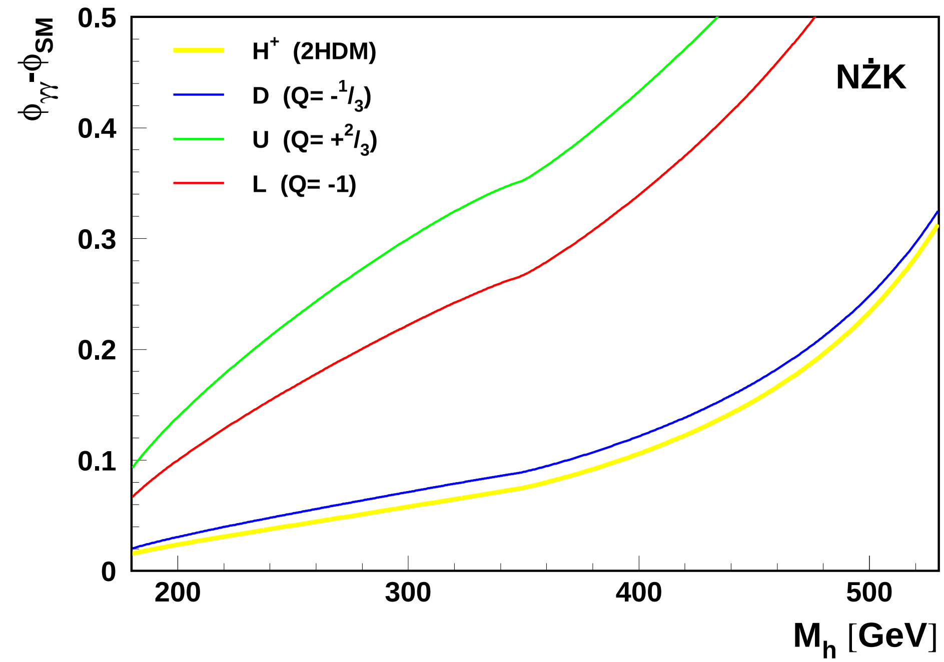
$\Rightarrow$ $\Gamma_{\gamma\gamma}$ little sensitive to new particles !

Expected deviations from SM

Contribution to $\Gamma_{\gamma\gamma}$ and $\phi_{\gamma\gamma}$ from new heavy charged particles with mass ~800 GeV
For SM with fourth-generation fermions and for SM-like 2HDM (II) type A
(additional contribution due to charged Higgs boson)

width — hep-ph/0207294 — phase





$\Rightarrow$ little effect on $\Gamma_{\gamma\gamma}$ for $M_h \sim$ 350 GeV

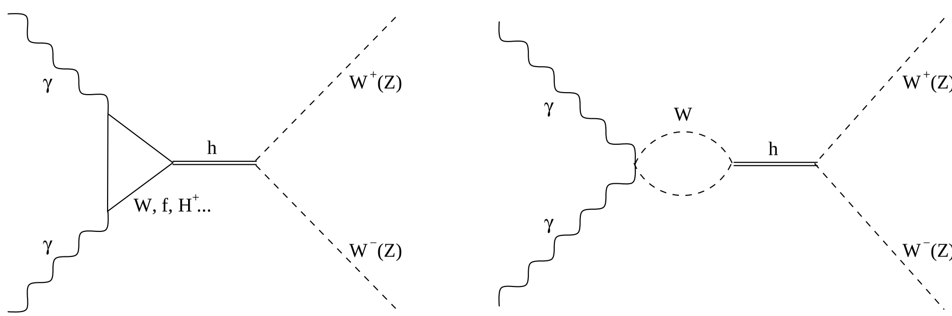
$\Rightarrow$ significant change in $\phi_{\gamma\gamma}$

Can we measure it !?

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

Higgs signal

For $M_h > 2\ M_W$ (phase $\phi_{\gamma\gamma} \neq 0$) decays to W^+W^- dominate:



"resonant"

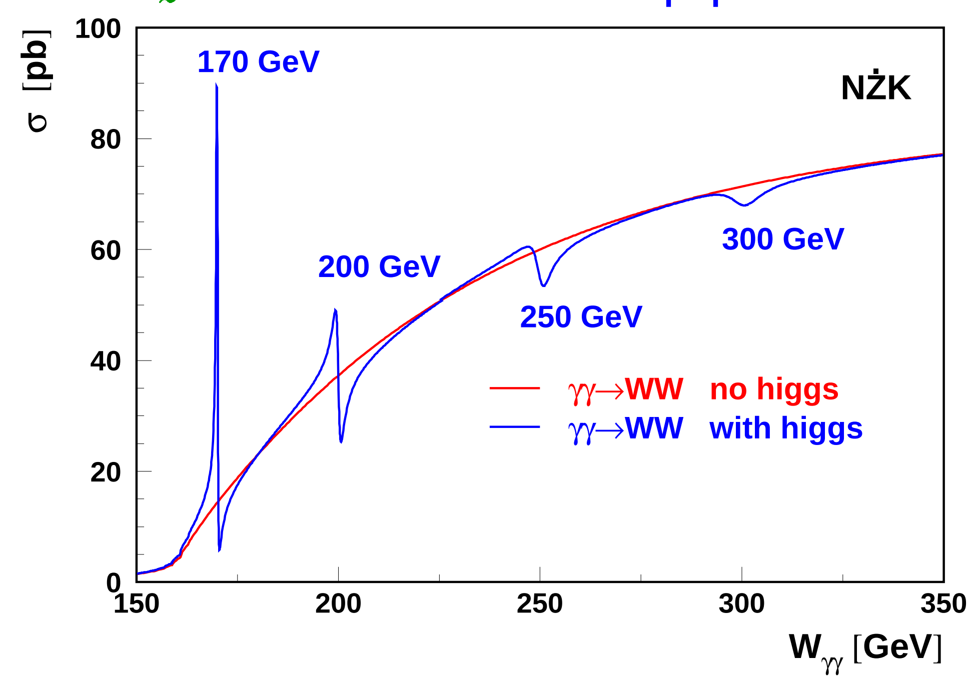
There is a large background from "direct", non-resonant production $\gamma\gamma \to W^+W^-$

Interference

Resonant and direct amplitudes interfere

Large effects expected:

$J_z = 0$ hep-ph/0207294



Destructive interference dominates above $\sim$ 200 GeV

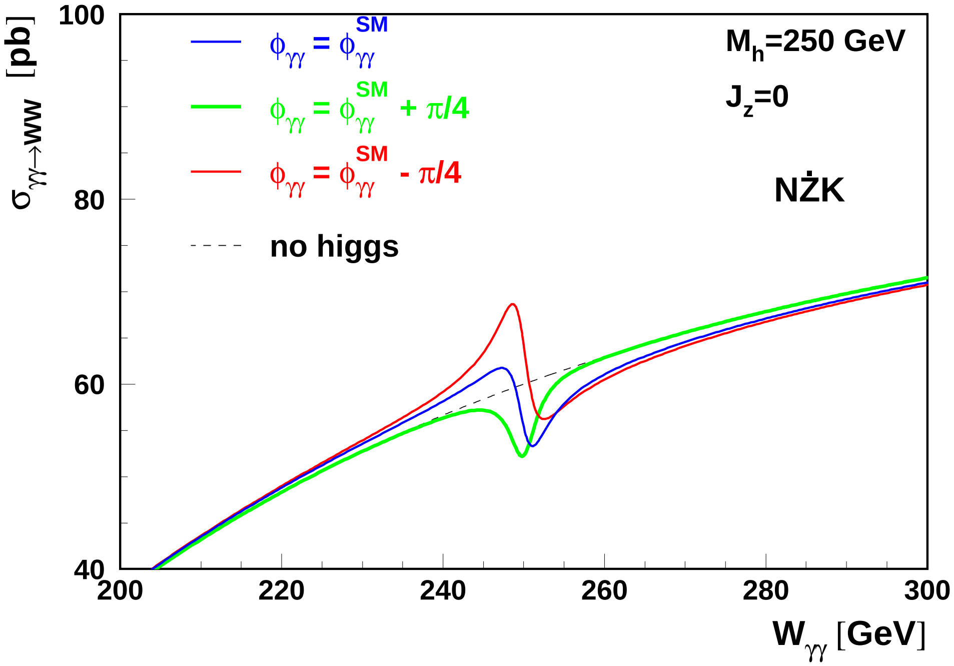
G.Belanger, F.Boudjema, Phys.Lett.B288 (1992) 210;
D.A.Morris, et al., Phys. Lett. B323 (1994) 421;
I.F.Ginzburg, I.P.Ivanov, Phys. Lett. B408 (1997) 325.

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

Phase measurement

Interference term is sensitive to the phase $\phi_{\gamma\gamma}$ of the $\gamma\gamma \to h$ amplitude

$\sigma(\gamma\gamma \to W^+W^-)$ dependence on $\phi_{\gamma\gamma}$



⇒ can be measured !

$\gamma\gamma \to ZZ$

Non-resonant background only at loop level

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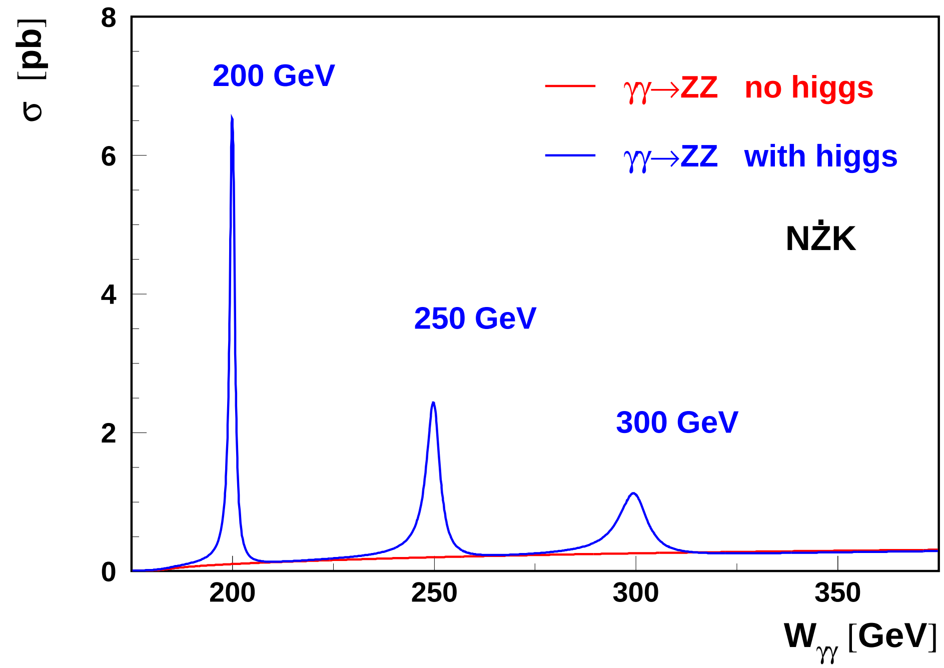


⇒ small interference effects

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

Analysis

Simulation

$\gamma\gamma$ spectra from **CompAZ**

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

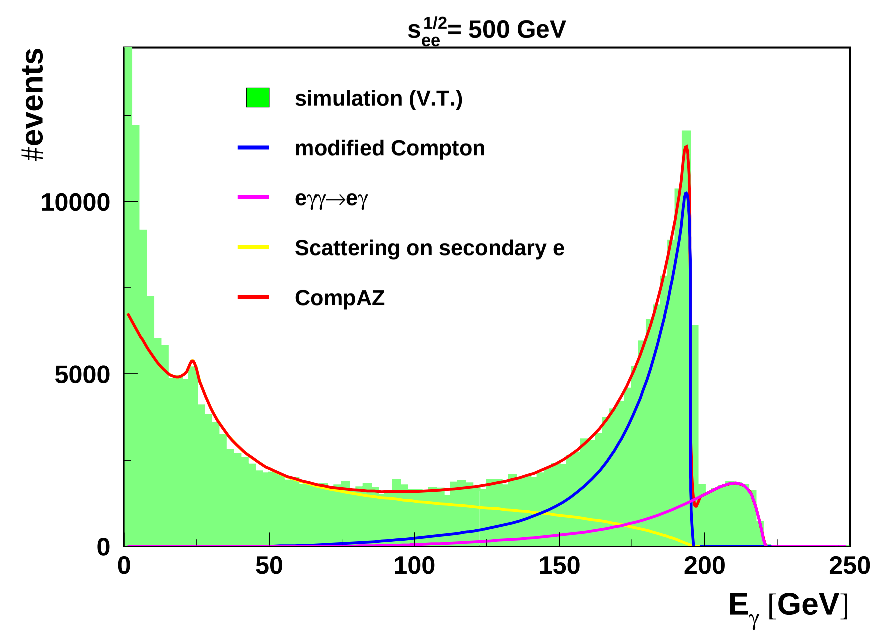
CompAZ

Parametrization of the Photon Collider luminosity spectra $\Rightarrow$ hep-ex/0207021

Based on the detailed simulation by V.Telnov
NIM A355(1995)3, NIM A472(2001)267

Higher order QED effect taken into account.

Comparison with detailed simulation:



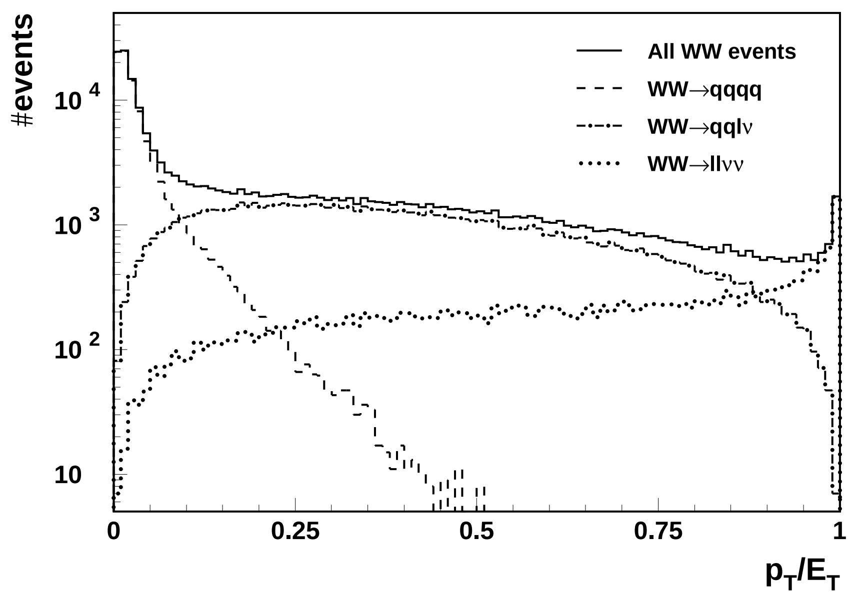
Analysis

W^+W^- event selection

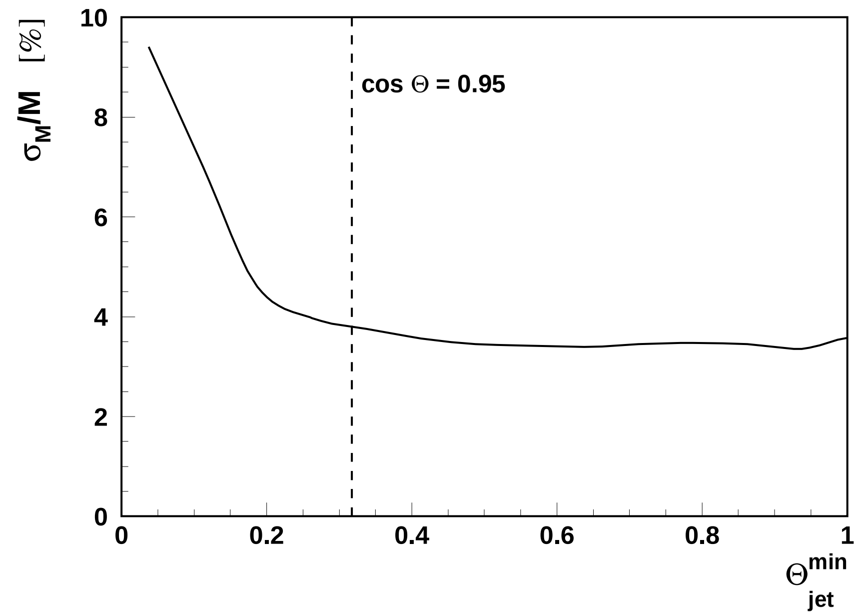
Selection requirements:

- balanced transverse momentum:

  $P_T/E_T < 0.1$



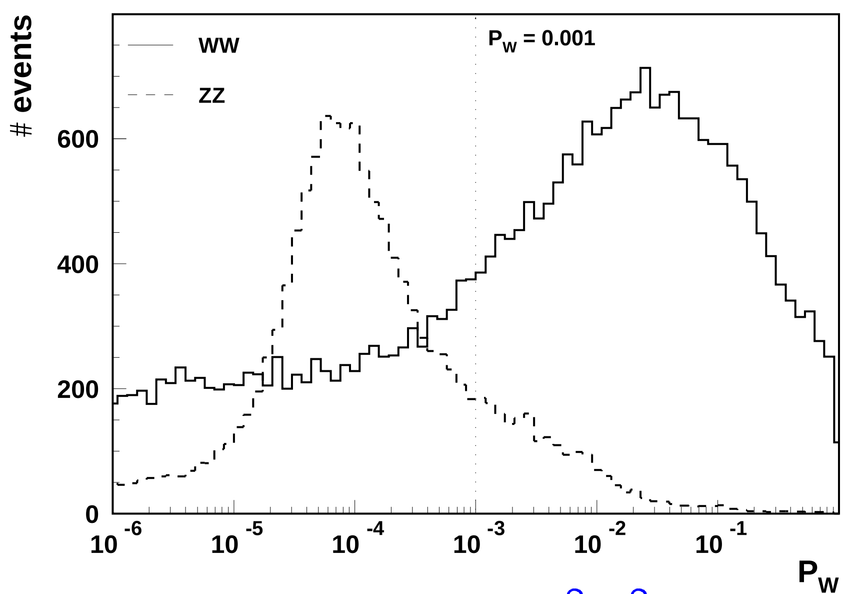
- 4 hadronic jets reconstructed
  (Durham algorithm)
- cut on jet angle $\cos\theta_{jet} < 0.95$
  to preserve good mass resolution



Analysis

W^+W^- event selection

- two $W^\pm$ reconstructed
  with probability $P_W > 0.001$



$$P_W = \prod_{W_1,W_2} \frac{M_W^2 \Gamma_W^2}{\left(m_{jj}^2 - M_W^2\right)^2 + M_W^2 \Gamma_W^2}$$

$\Rightarrow P_W = 1$ for "perfect" W pair fit

ZZ event selection

Very similar to W^+W^- selection:

- balanced transverse momentum:
  $P_T/E_T < 0.1$
- 2 leptons ($e^\pm$ or $\mu^\pm$) + 2 hadronic jets
  too large background in 4-jet channel
- cut on lepton and jet angle $\cos\theta_{l,jet} < 0.95$
- leptons and jets reconstruct into two Z°
  with probability $P_Z > 0.001$

Selection efficiency

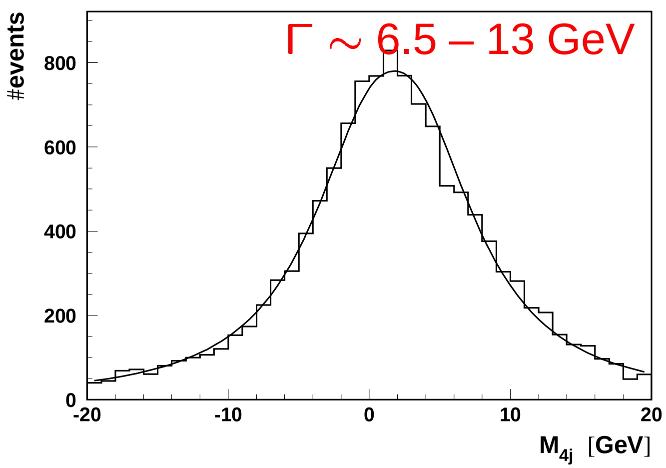
- 16 (20) % for W^+W^- events
  for M_h= 200 (400) GeV.
- ~5 % for ZZ events

$BR(ZZ \rightarrow q\bar{q}\, l^+l^-) \approx 9.4\%$ $(l = \mu, e)$

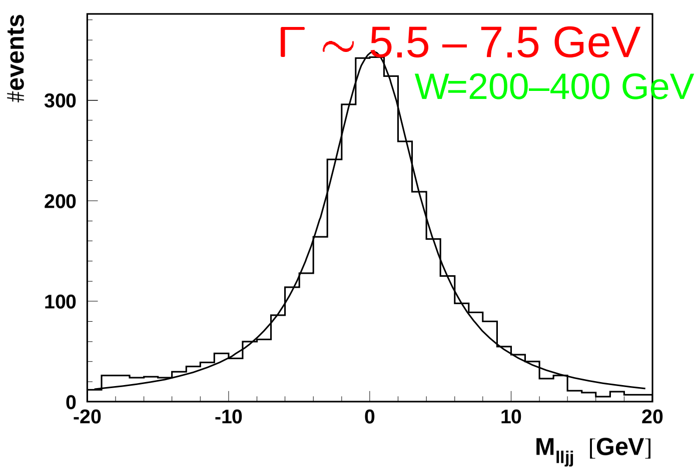
Analysis

Mass resolution

$\gamma\gamma \to W^+W^- \to$ 4 jets



$\gamma\gamma \to ZZ \to l^+l^-$ + 2 jets



Parametrization

Invariant mass resolution for selected W^+W^- and ZZ events is parametrized as a function of $W_{\gamma\gamma}$.

"Measured" invariant mass distribution can be then described by convolution of:

- Analytical luminosity Spectra **CompAZ**
- Cross section formula
  for signal + background + interf.
- Invariant mass resolution

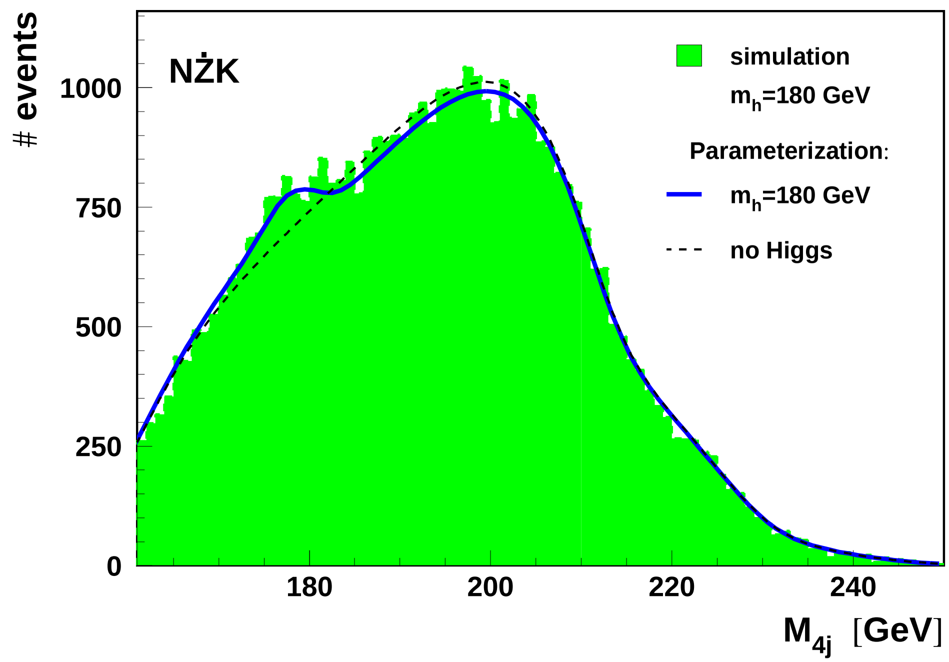
$\Rightarrow$ expected mass spectra can be calculated for any $\sqrt{s_{ee}}$ and M_h without time-consuming MC simulation

Analysis

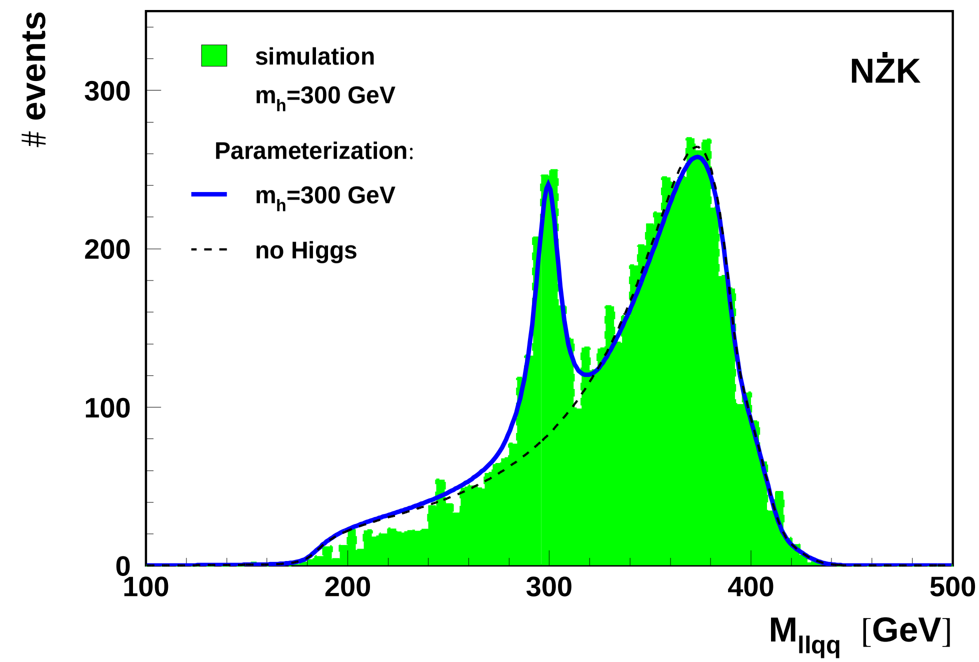
Parametrization

Comparison of parametrized detector response with full simulation (PYTHIA+SIMDET):

W^+W^-



ZZ



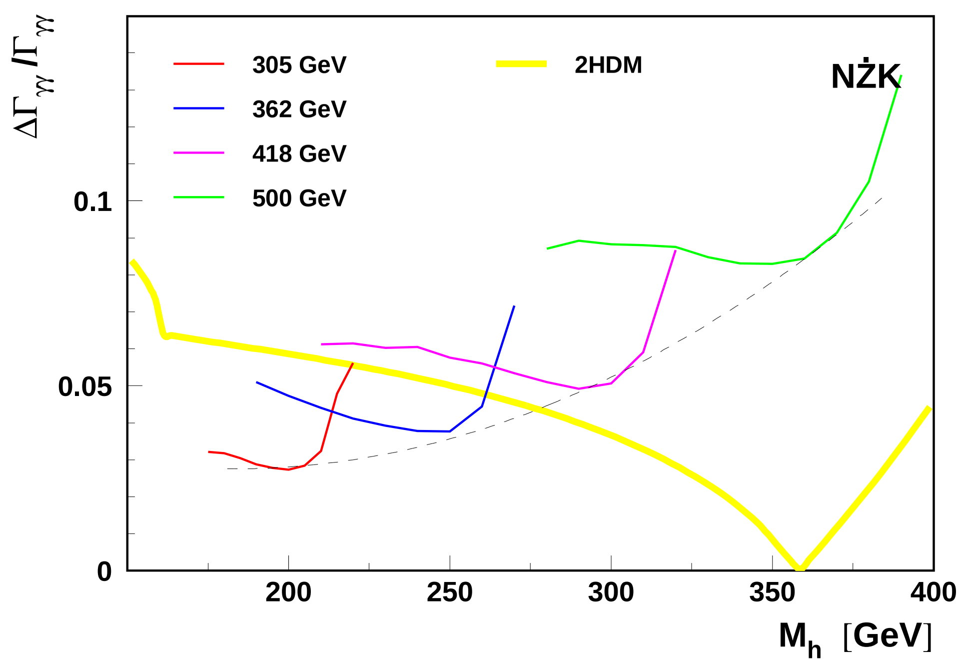
Parametrization was used for fast simulation of multiple experiments for different $\sqrt{s_{ee}}$ and M_h, and for fitting model parameters $\Gamma_{\gamma\gamma}$ and $\phi_{\gamma\gamma}$ to generated mass distributions.

SM results

$\Gamma_{\gamma\gamma}$ measurement

One parameter fit to invariant mass distribution for W^+W^- and ZZ events

⇒ Average statistical precision (1 PC year):



assuming SM branching ratios

Sensitive to possible "new physics" only up to $M_h \sim 280$ GeV

For higher Higgs masses $\Gamma_{\gamma\gamma}$ is little sensitive to contribution of new heavy charged particles !

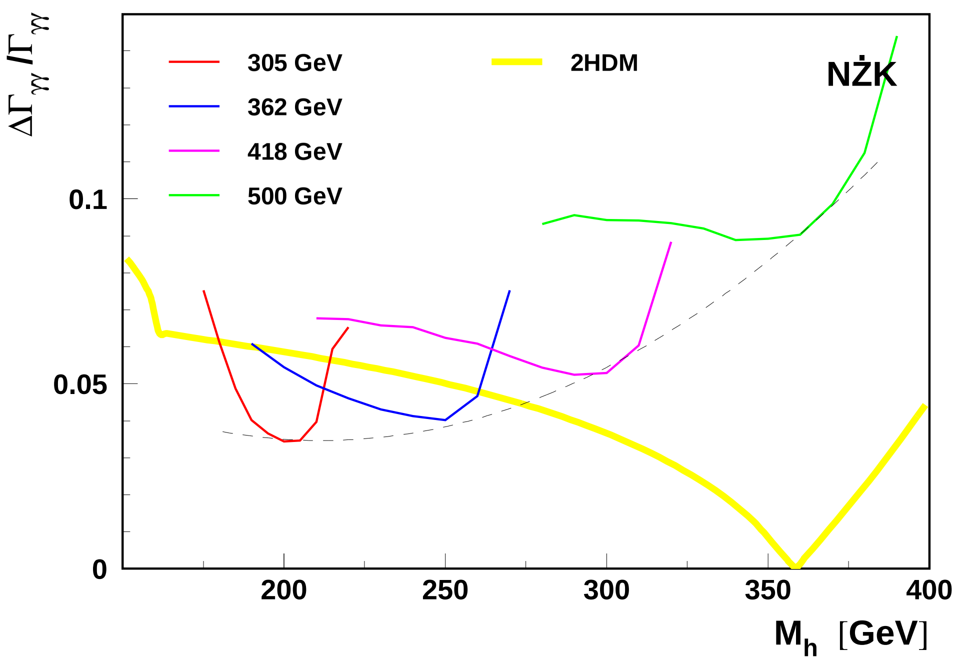
"new physics" modeled by SM-like 2HDM (II) with $M_{H^+} = 800$ GeV

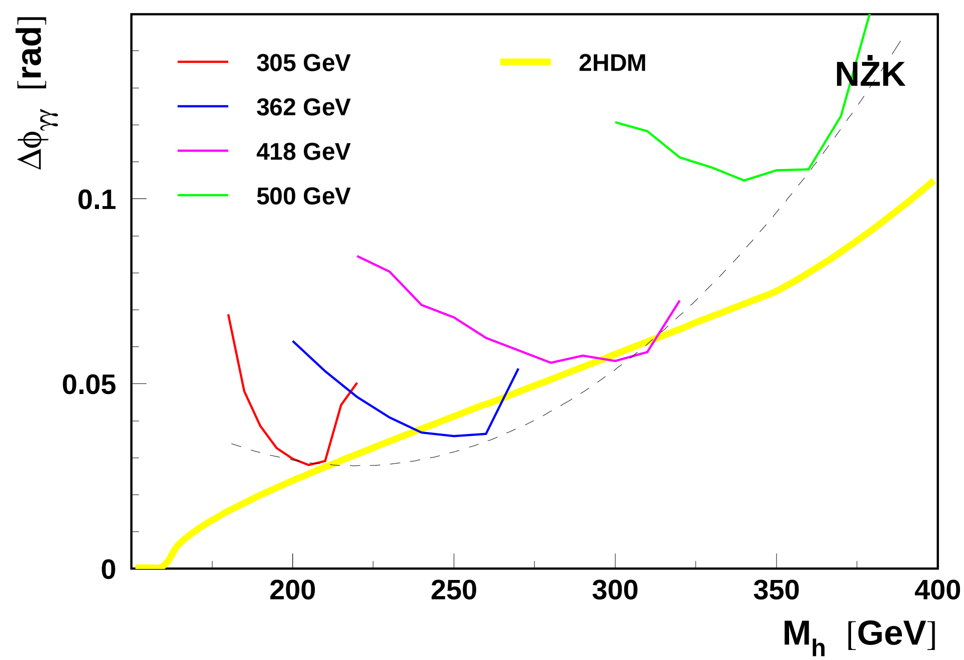
SM results

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 $M_{H+} = 800$ GeV
at large Higgs boson masses

SM results

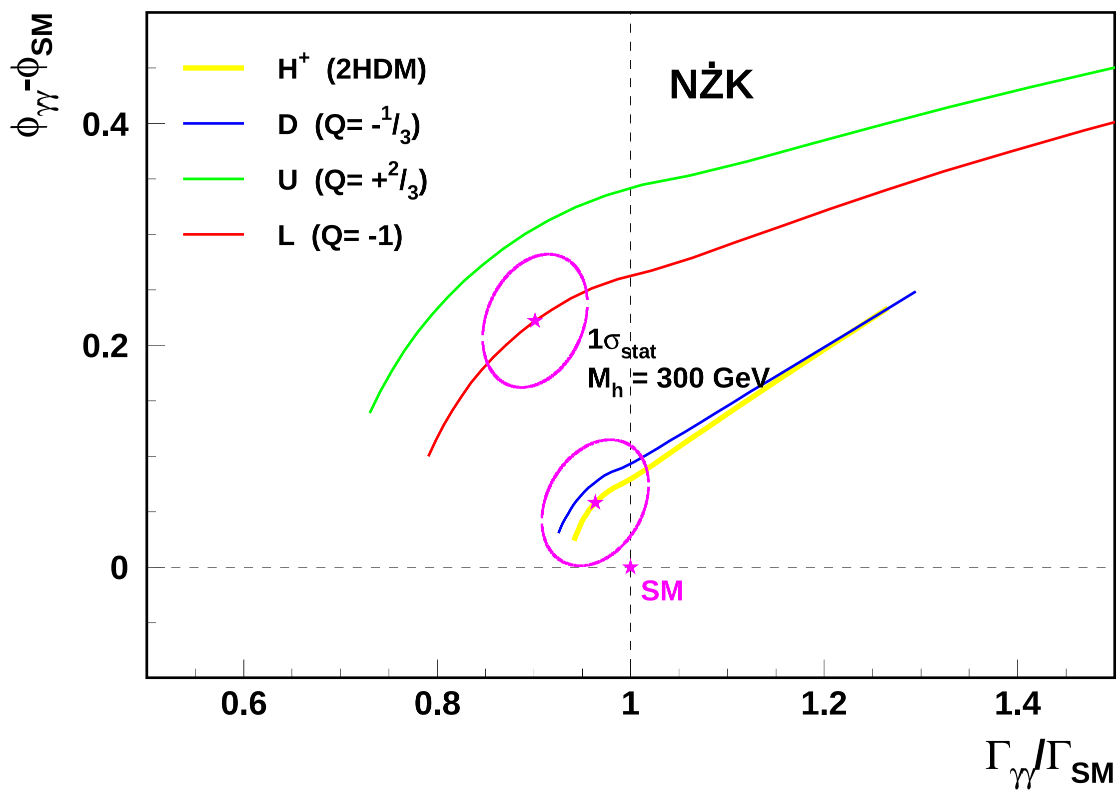
Expected statistical error contours (1σ) in $\phi_{\gamma\gamma} - \Gamma_{\gamma\gamma}$, for $M_h = 300$ GeV:

4^{th} generation lepton

$M_L = 800$ GeV $\Rightarrow$

SM-like 2HDM (II) $\Rightarrow$

$M_{H+} = 800$ GeV



$\Rightarrow$ separation not possible without phase measurement !

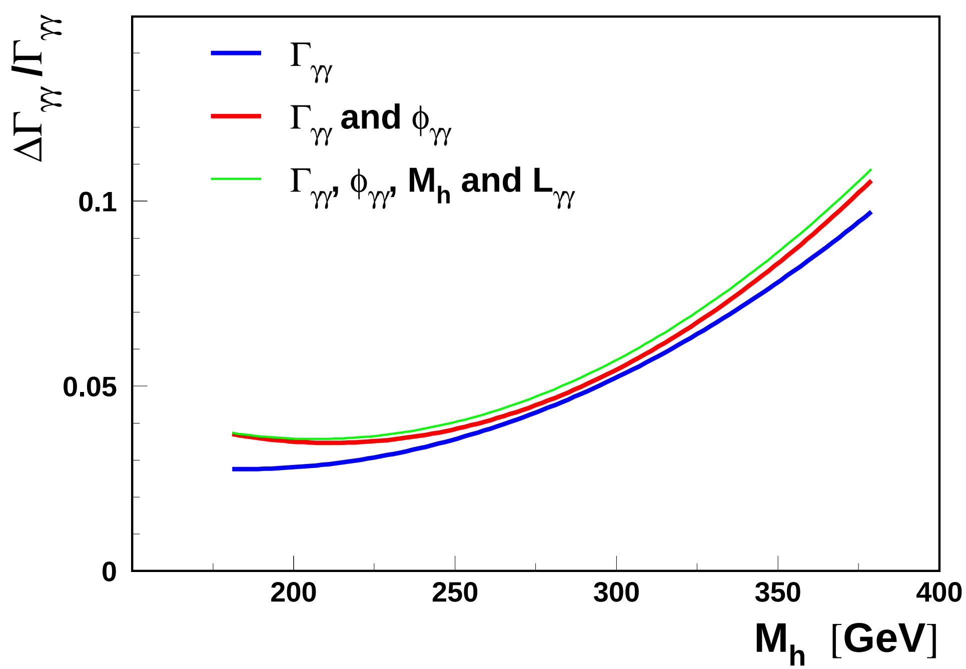
Two parameter fit to W^+W^- and ZZ invariant mass distribution; one year of Photon Collider running.

SM results

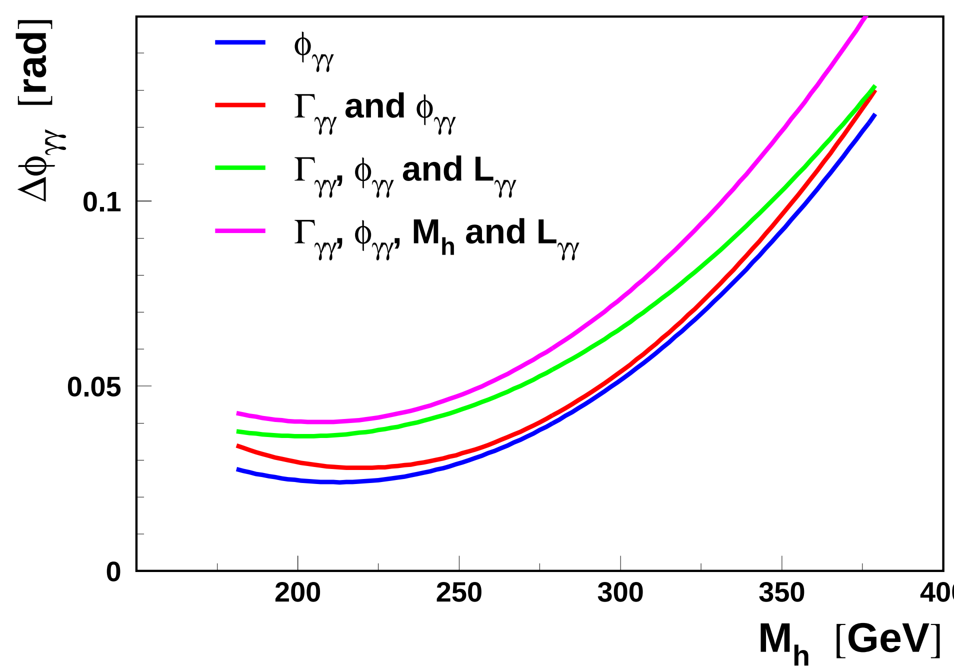
Systematic effects

Statistical precision for different choices of fit parameters:

$\Gamma_{\gamma\gamma}$



$\phi_{\gamma\gamma}$



Precize knowledge of M_h and luminosity not crucial
⇒ can be constrained by the data itself

⇒ sensitive to M_h and luminosity uncertainty

2HDM(II)

SM-like 2HDM(II)

Solution A:

$$g_u = g_d = g_V = 1$$

g_i - couplings normalized to SM couplings

All Higgs couplings are the same as in SM.

Only $\Gamma_{\gamma\gamma}$ and $\phi_{\gamma\gamma}$ are affected by the loop contribution from heavy charged Higgs

However, scalar loops give very small contribution to $h \to \gamma\gamma$...

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

Solution B (extended)

$$g_d = -g_u = 1$$
$$g_v = \cos 2\beta$$

$$(g_v - g_d)(g_u - g_v) + g_v^2 = 1$$

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

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

At LHC will also look SM-like:

Production is dominated by gg-fusion

$$\sigma(pp \to h) \sim \Gamma_{gg}$$

and Γ_{gg} is dominated by t loop...(g_u)

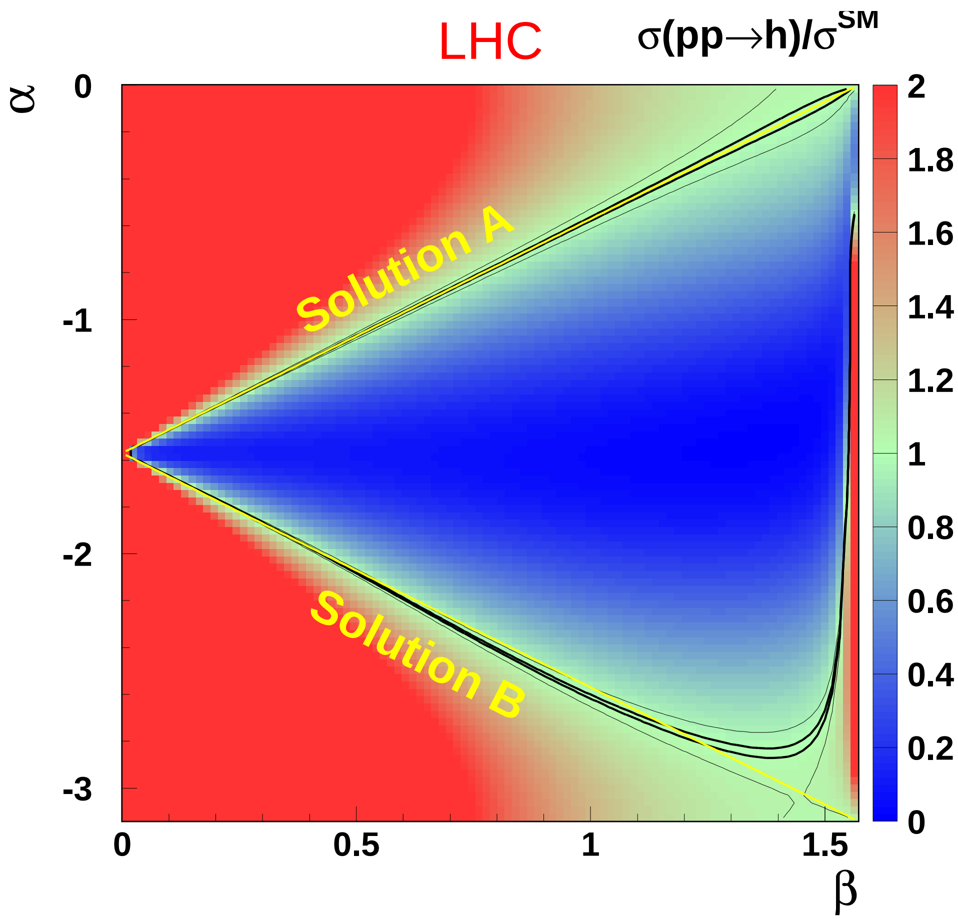
Deviations from SM can be measured at LHC only for $\tan\beta \sim 1$

$\Rightarrow g_v \sim 0 \Rightarrow b\bar{b}$ decays visible

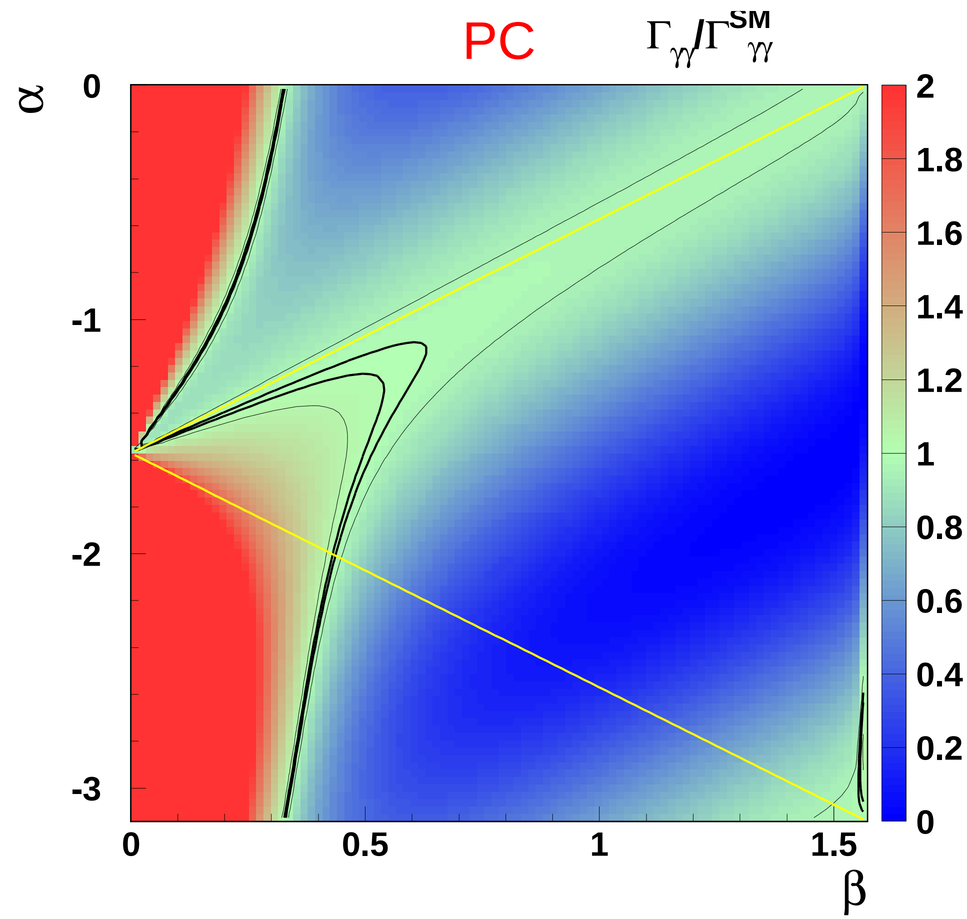
2HDM(II)

Higgs production cross section compared to SM M_h=300 GeV

LHC



PC



black contours: ± 1 and $\pm 5\%$ deviations

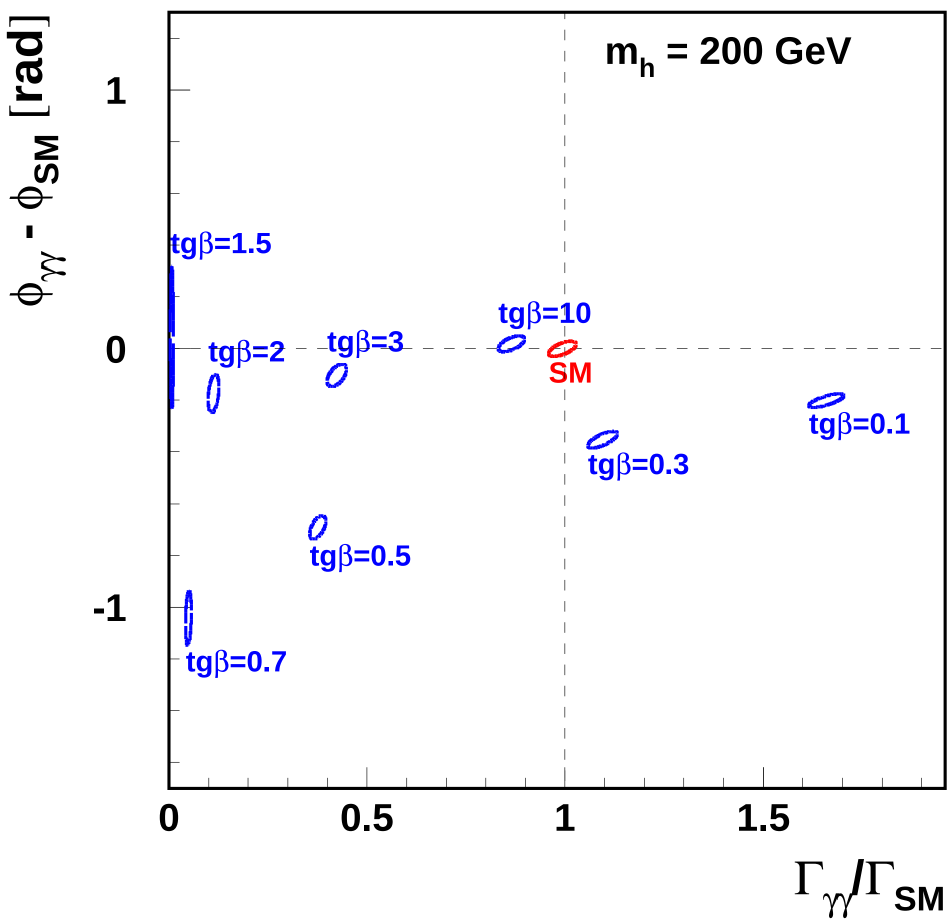
$\Rightarrow$ significant effects in solution B

2HDM(II)

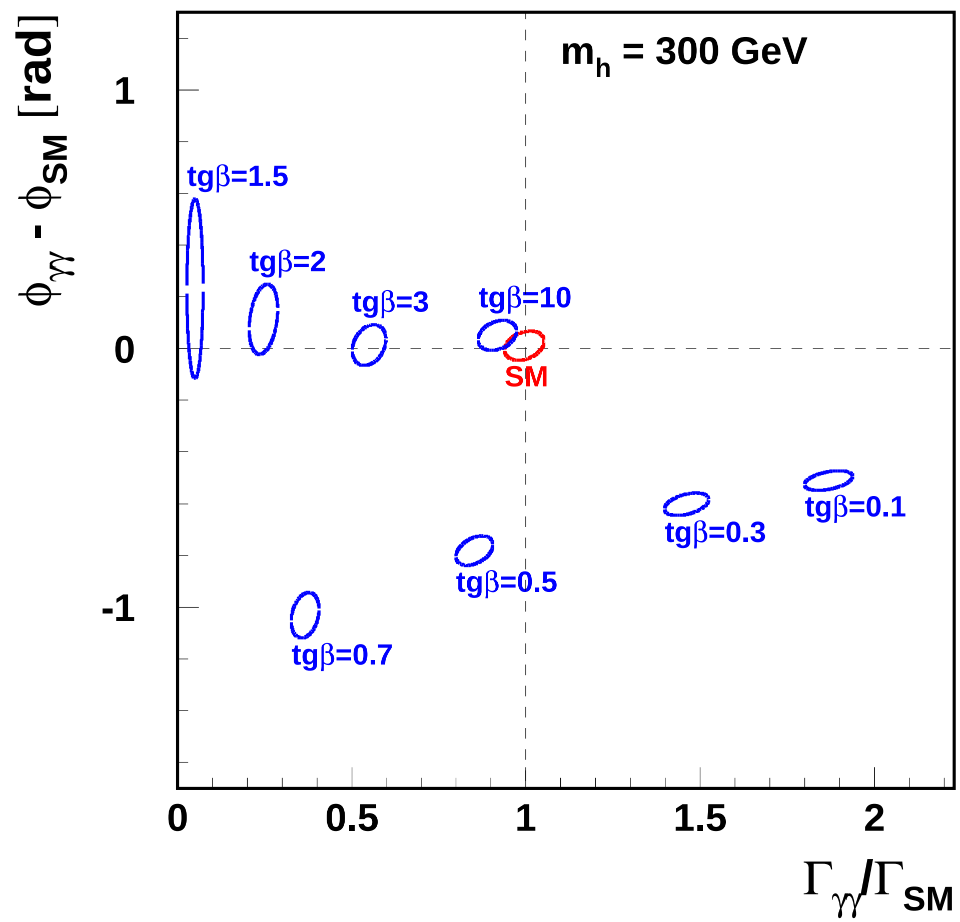
Solution B SM-like

Two-photon width and phase measurement for different $\tan\beta$

M_h = 200 GeV



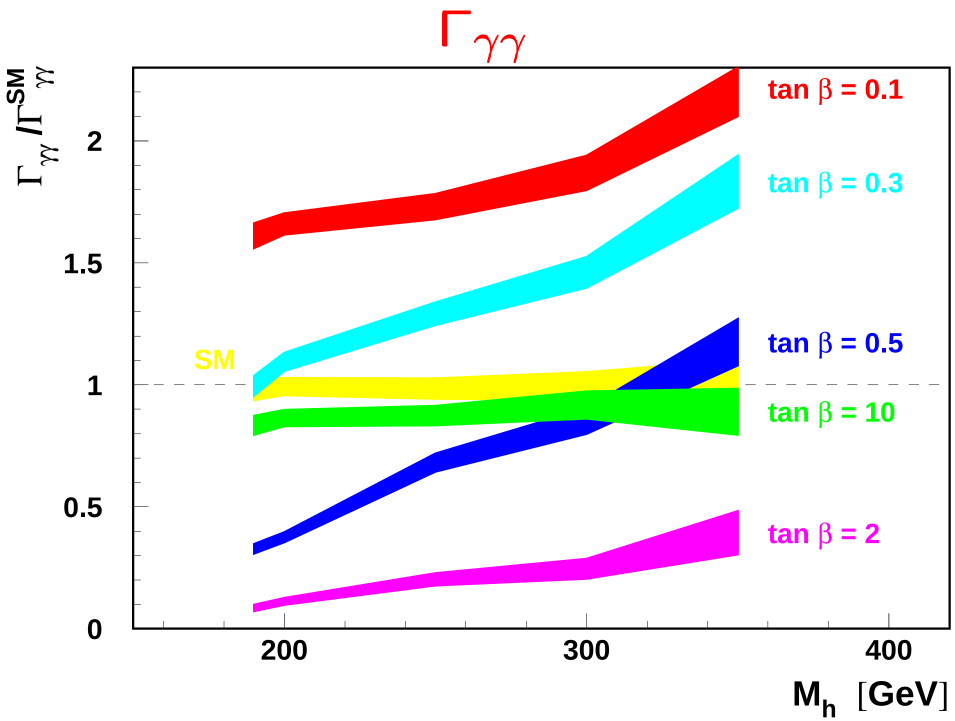
M_h = 300 GeV

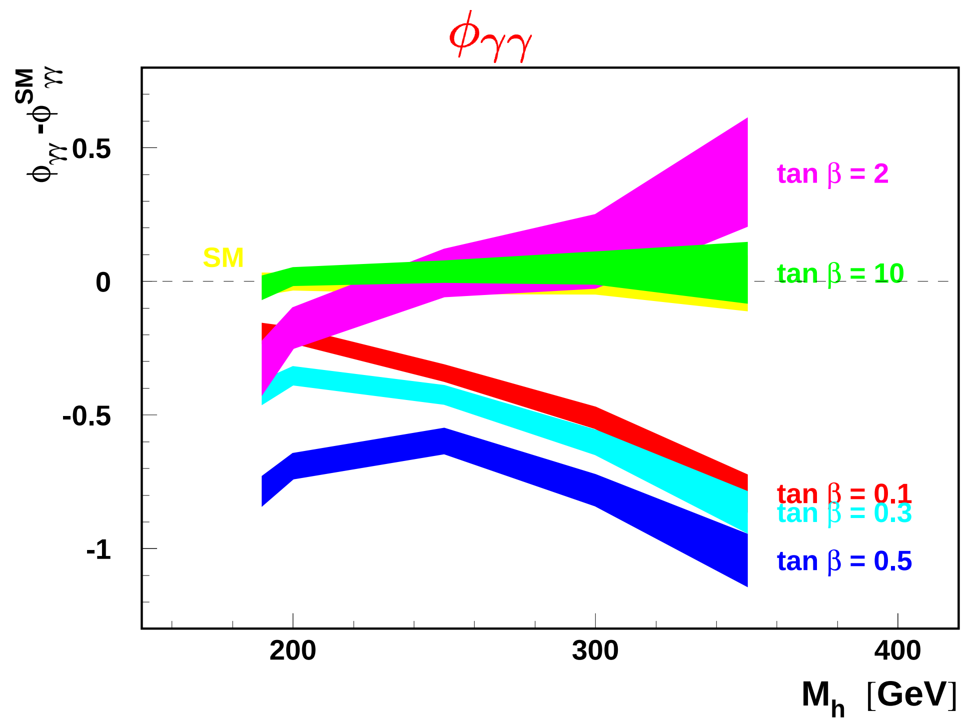


2HDM(II)

Solution B SM-like

Two-photon width and phase measurement for different M_h
band width indicates statistical measurement error





Measurement of both phase and width can help to test Higgs sector structure
e.g. distinguish between large and small $\tan\beta$

Summary

Production of the SM Higgs-boson in $\gamma\gamma \rightarrow h$ studied for masses above 170 GeV

Large interference effects are expected in the W^+W^- decay channel

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

For Higgs boson masses around 300 GeV the amplitude phase $\phi_{\gamma\gamma}$
can be more sensitive to the contributions of new particles than the $\Gamma_{\gamma\gamma}$

Large effects expected for SM-like solution B of 2HDM (II) (looks like SM at LHC)

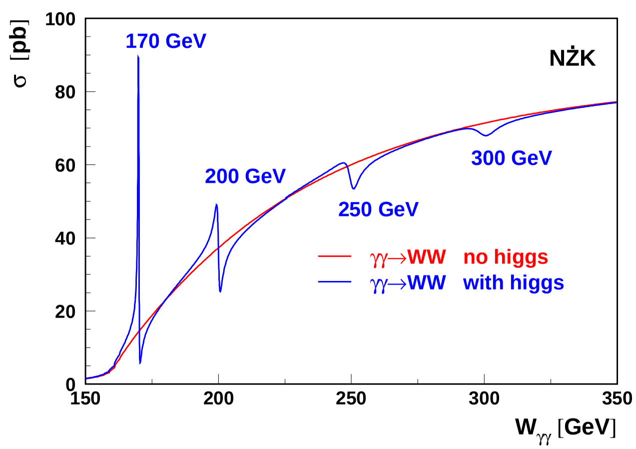
Measurement of $\phi_{\gamma\gamma}$ can be helpful in testing Higgs sector structure

Two-photon width and phase measurement from $h \to WW,\ ZZ$

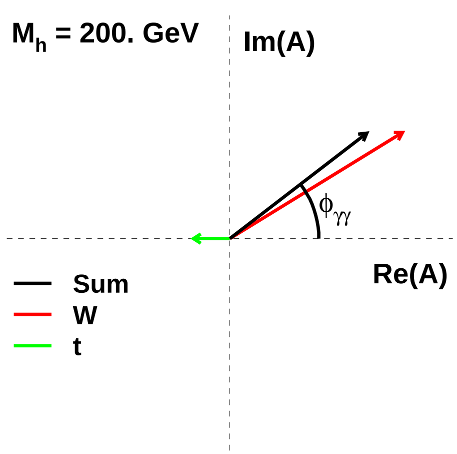
P. Nieżurawski, A.F. Żarnecki and M. Krawczyk

hep-ph/0207294

Large interference effects in
$\gamma\gamma \to (h) \to WW$

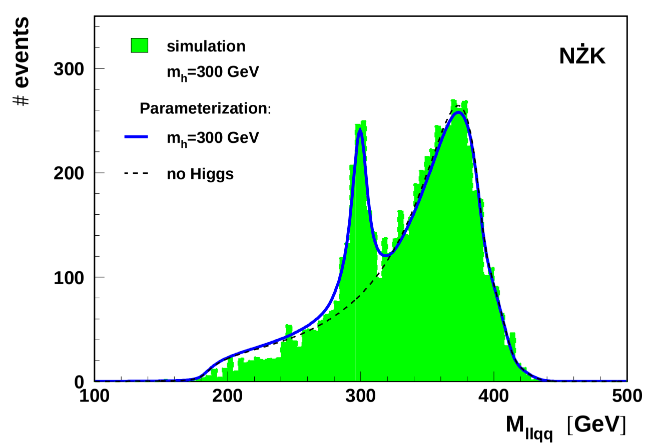


$\Rightarrow$ possible measurement of
$\gamma\gamma \to h$ amplitude phase

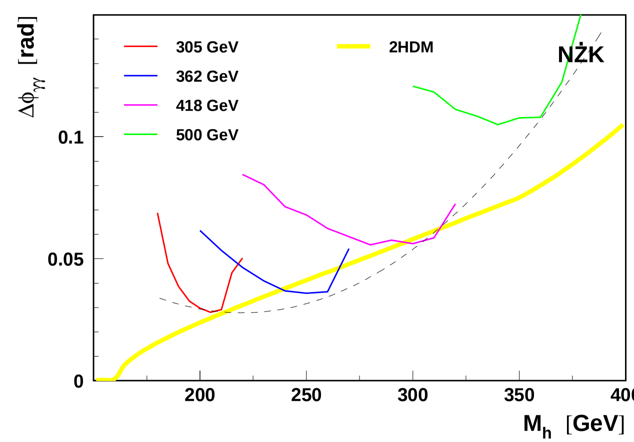


Simulation based on realistic luminosity spectra (V.Telnov), PYTHIA and SIMDET detector simulation.

Fast extrapolation to different $\sqrt{s_{ee}}$ and M_h based on CompAZ and detector response parametrization.



For $170 < M_h < 350$ GeV
$\Gamma_{\gamma\gamma}$ can be measured to 3 to 9%
$\phi_{\gamma\gamma}$ to 30 to 110 mrad



Large effects expected for
SM-like solution B of 2HDM (II)

Measurement of $\phi_{\gamma\gamma}$ can be helpful in testing Higgs sector structure