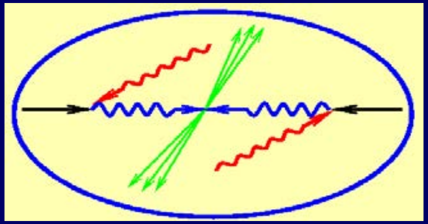
LCWS2013

Tokyo U., 12.11.2013

Testing Higgs Physics at PLC

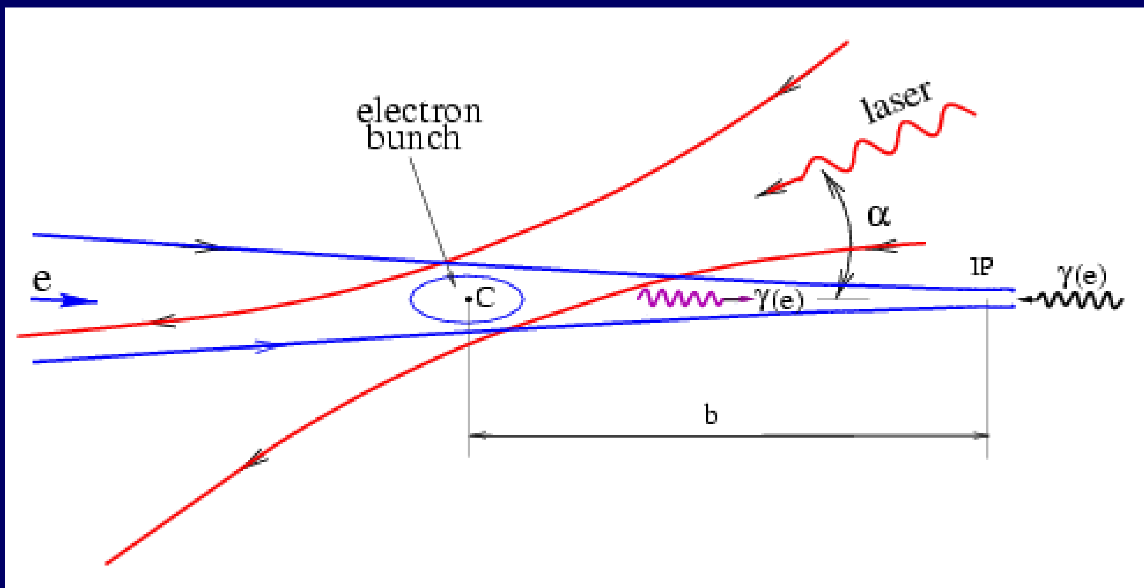


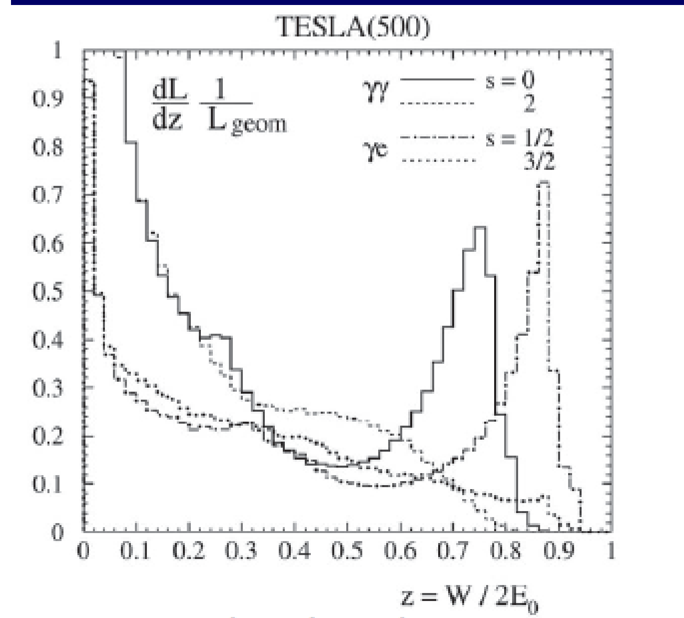
1981 concept of Photon Collider
…2000 PLC workshop….

Maria Krawczyk
University of Warsaw

Backward Compton scattering- a basic idea of the photon collider

Ginzburg, Telnov, Serbo, Kotkin ’81





- PLC = γ γ and e γ options

PLC - main characteristics

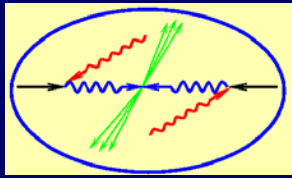
- Variable energy and degree of polarization of the photon beams – both circular and linear polarization; in $\gamma\gamma \to O^{+}(2)$ resonance
- Almost monochromatic spectrum possible (a high energy peak)

PLC at ILC

- For ILC with energy 500-1000 GeV (ILC Report 2007)
- Energy $E_{\gamma\gamma}$ up to 0.8 E_{ee} (0.9 for $e\gamma$ option)
- Luminosity $\gamma\gamma$ (peak) ~ 0.1-.2 L_{ee} (geom) peak: $E_{\gamma\gamma} > 0.65\ E_{ee}$
  → annual $\gamma\gamma$ L= 84 fb^{-1} in the peak for 120 GeV (total 410 fb^{-1})
- Mean energy spread in the $\gamma\gamma$ peak (cut): ~ 5 – 7 %
- Mean helicity at the peak: 90 - 95 %
- Important parameter x: max $E_{\gamma} = x/(1+x)E_{e}$

x=4.5 to avoid e+e- pair production

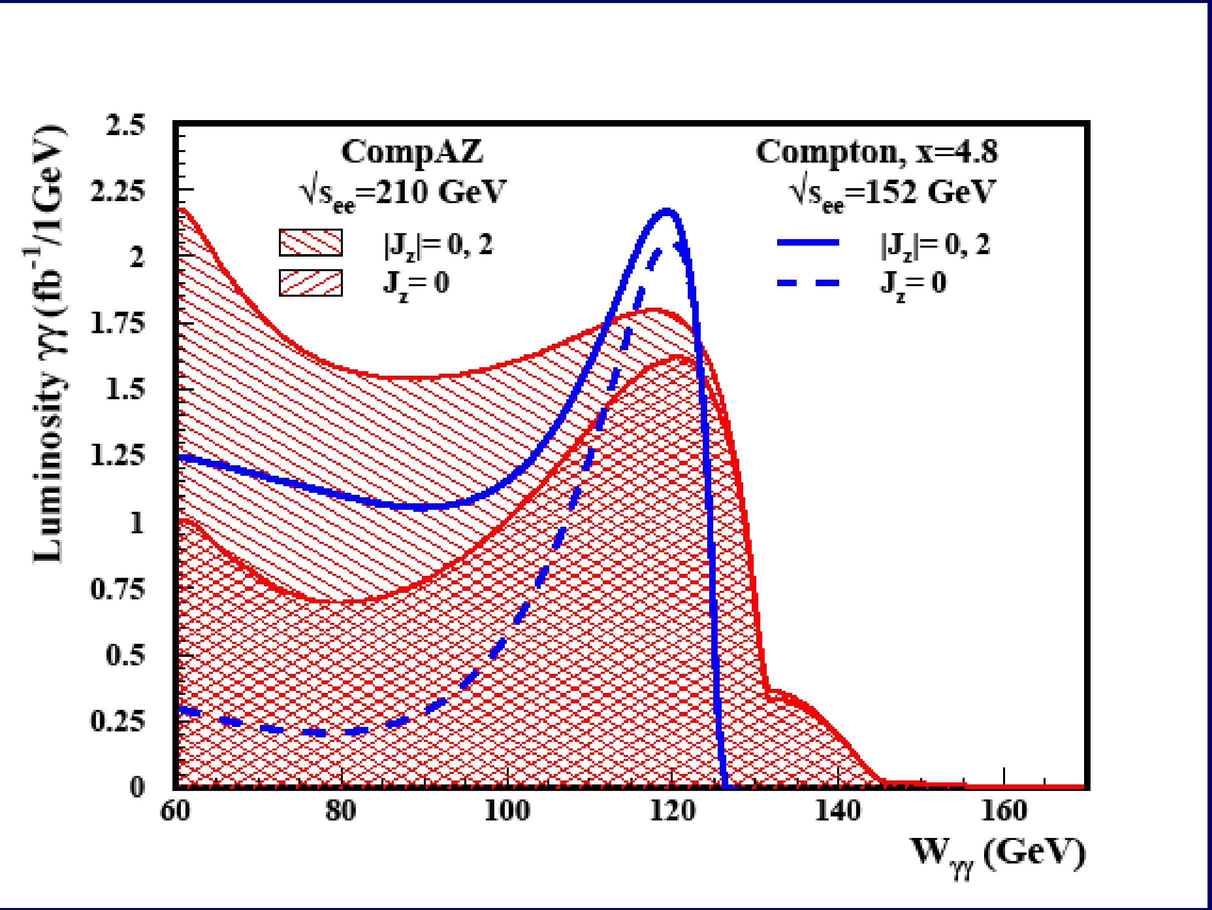
PLC: Photon Linear Collider



$\gamma\,\gamma$ and e γ

- Resonance production of C=+ J=0,2 states (Higgs) Ginzburg et al
- Higher mass reach than at e^+e^- (Higgs, SUSY) Spira, Zerwas,
- Polarised beams – CP filter Gunion, Grzadkowski,Hagiwara, Godbole, Zarnecki…
- H $\gamma\,\gamma$ coupling – sensitivity to charged particles in theory (nondecoupling) Ginzburg et al.., Gunion..
- Direct production of charged scalars, fermions and vectors – higher cross section Kanemura, Moenig, Belanger
- Pair production of neutral particles
  – selfinteraction, light-on-light Jikia,Gounaris,Hagiwara,Kanemura,Velasco
- Study of hadronic interaction of the photon Godbole,Pancheri; MK Brodsky, deRoeck, Zerwas

Important : realistic γ γ spectra (Telnov)



Blue – an ideal spectrum

For J_z = 0, 2

Here J_z=0 peak for M=120 GeV

CompAZ parametrization (A.F.Żarnecki)

LHC

SM-like Higgs particle with mass~125 GeV observed at ATLAS+CMS (+Tevatron)

BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

F. Englert and R. Brout
Faculté des Sciences, Université Libre de Bruxelles, Bruxelles, Belgium
(Received 26 June 1964)

BROKEN SYMMETRIES, MASSLESS PARTICLES AND GAUGE FIELDS

P. W. HIGGS
Tait Institute of Mathematical Physics, University of Edinburgh, Scotland
Received 27 July 1964

Nobel 2013 (Englert, Higgs)

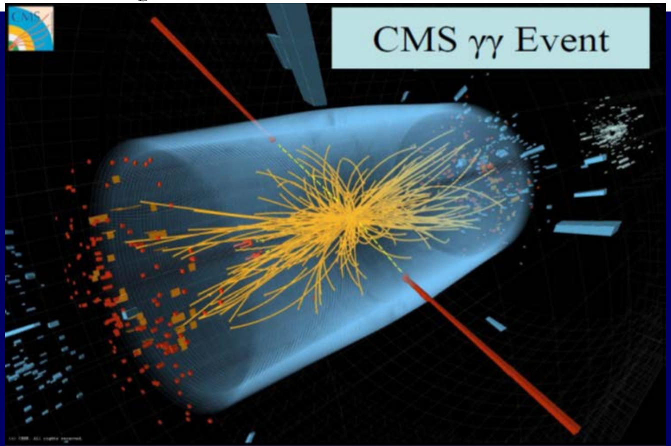
VOLUME 13, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1964

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

GLOBAL CONSERVATION LAWS AND MASSLESS PARTICLES*

G. S. Guralnik,† C. R. Hagen,‡ and T. W. B. Kibble
Department of Physics, Imperial College, London, England
(Received 12 October 1964)



Important loop couplings

ggH,γγH,ZγH,

125 GeV particle $\mathcal{H}$

What it is?

H_{SM} - Higgs boson of SM ?

h or heavier scalar

(eg. H of CP-conserving 2HDM (MSSM)?

other state ?

SM-like scenario is observed

all measured $\mathcal{H}$ couplings are close to

the SM-prediction for *absolute value*

Four interpretations of these data possible

1. with all tree-level couplings as in the SM
2. with all these couplings close to SM-values beside tt $\mathcal{H}$ ~ (-) tt H_{SM} (*wrong sign*)
3. as in 1. but in addition new *heavy charged* particles contributing to the loop couplings
4. the observed signal is not due to one particle but it is an effect of two or more particles, not resolved experimentally -- *the degenerated Higgses*

BSM: with modified vs SM $\mathcal{H}gg$, $\mathcal{H}\gamma\gamma$, $\mathcal{H}Z\gamma$

What PLC can do for

- 125 GeV $\mathcal{H}$

  SM-like scenarios 2HDM's

  2-photon width

  selfcouplings

- Heavy Higgs after discovery of $\mathcal{H}$

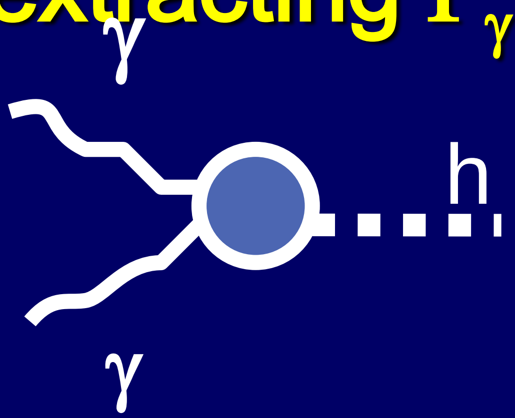
  MSSM wedge

  CP properties

- Resolving degenerate Higgses state $\mathcal{H}$

SM Higgs-resonance decaying in bb

→ extracting $\Gamma_{\gamma\gamma}$



Studies (simulations) for Mh=120 GeV:

- Ohgaki, Takahashi, Watanabe 1997
- Jikia, Soldner-Rembold 1999
- Asner, Gronberg, Gunion 2001
- Niezurawski, Zarnecki, MK 2002
- Moenig, Rosca 2003…..

Cross section x Br ~ 2 %

(+Br to bb from e+e- at 1%) →

3 % accuracy for $\Gamma_{\gamma\gamma}$

$\Gamma_{\gamma\gamma}$ sensitive charged new partices, charged Higgs bosons, new generations... Distinguishing SM-like scenarios possible
Note that hγγ vertex has a phase !!

125 GeV $\mathcal{H}$ at PLC ?

$$\gamma\gamma \to h \to b\bar{b}$$

$\Gamma\,(h \to \gamma\,\gamma) \sim 3\ \%$

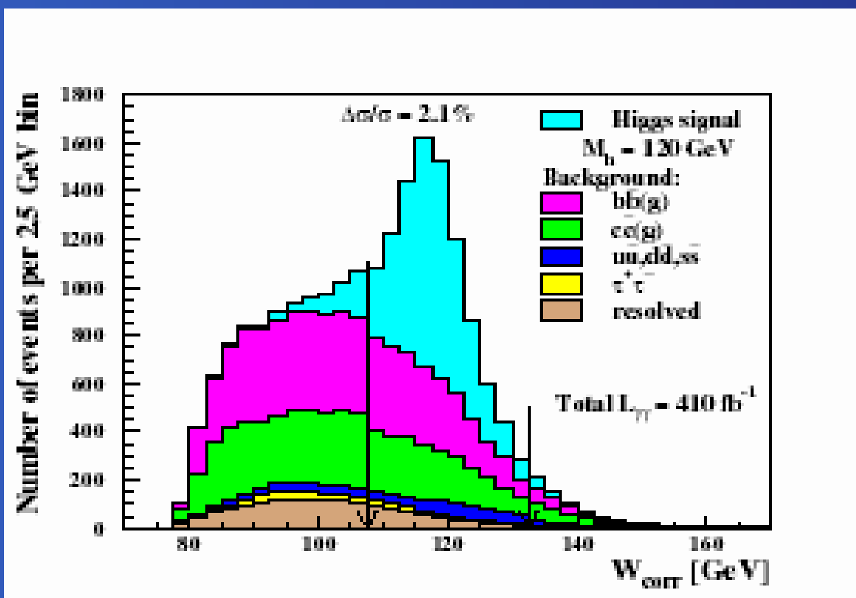
SM summary

NŻK

Niezurawski et al.,

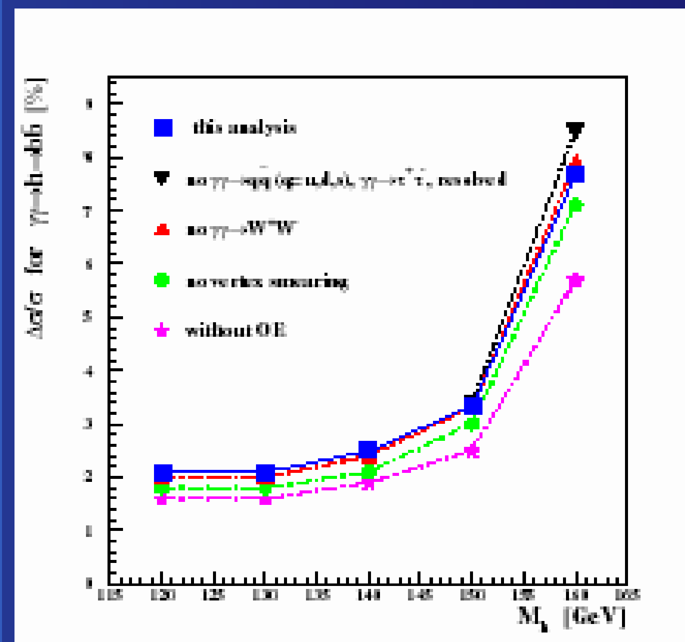
Monig, Rosca

→ Results for $M_h = 120$ GeV



Corrected invariant mass distributions for signal and background events

Results for $M_h = 120$-160 GeV

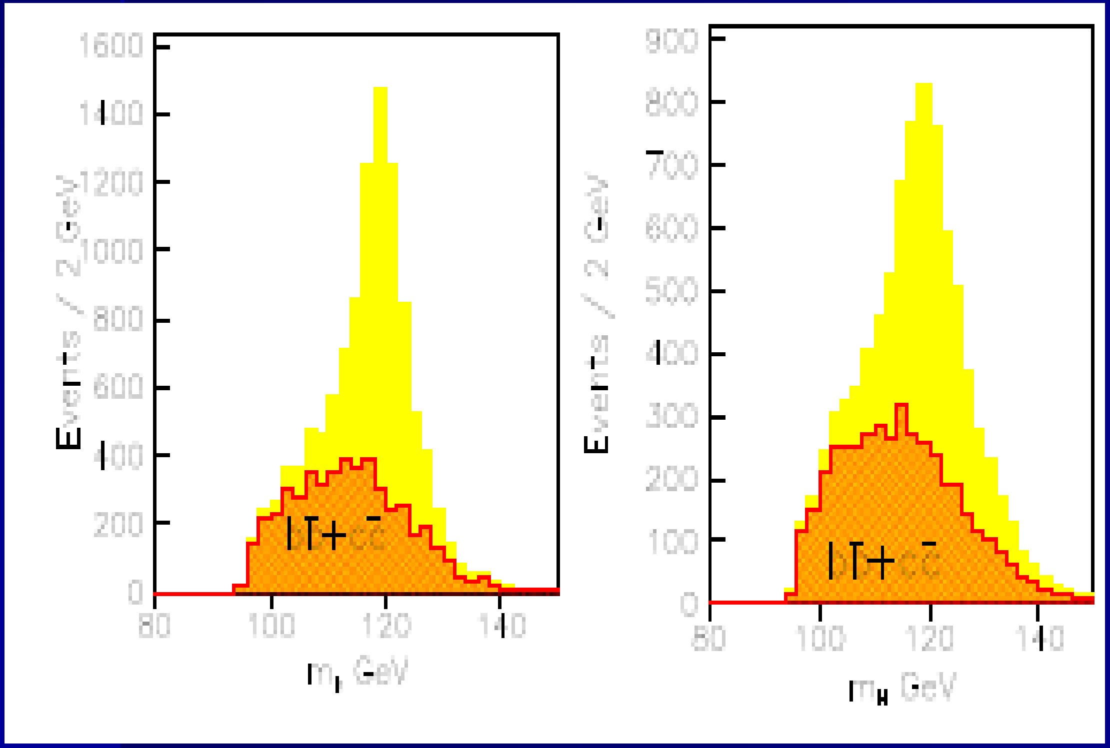


For $M_h = 150, 160$ GeV additional cuts to reduce $\gamma\gamma \to W^+W^-$

A. Rosca, K. Moening: hep-ph/0705.1259
SM Higgs 120 GeV at PLC

- Without and with overlying events

$$\frac{\Delta[\Gamma(H\to\gamma\gamma)\times BR(H\to b\bar{b})]}{[\Gamma(H\to\gamma\gamma)\times BR(H\to b\bar{b})]} = \sqrt{N_{obs}}/(N_{obs}-N_{bkg}) = 2.1\%.$$



2.1 %

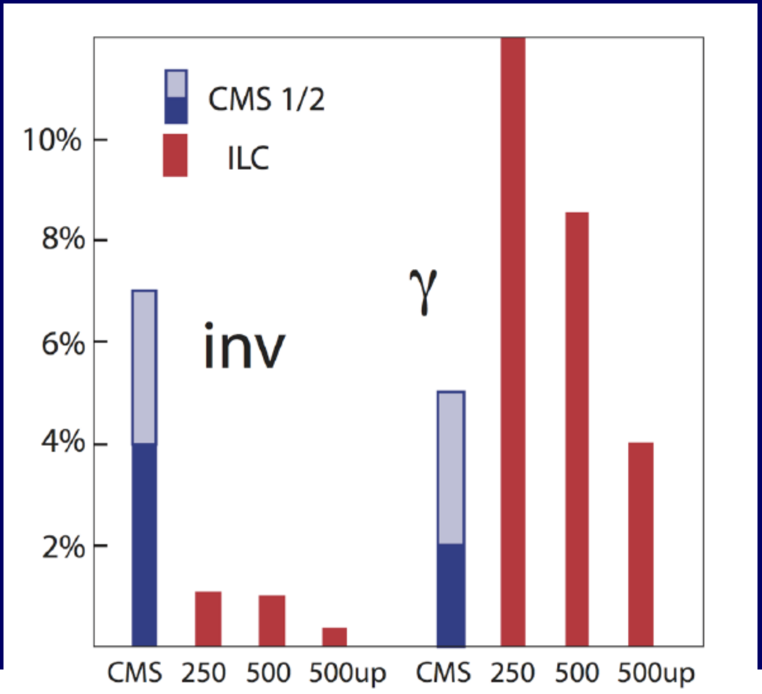
Knowing it and using Br

from e^+e^- ->

Γ(h->γ γ) » 3 %

LHC: signal strength
(~ $|g_H|^2/|g_{HSM}|^2$),
1.55+0.33−0.28 ATLAS
0.78 ±0.28/0.26 CMS

M. Peskin

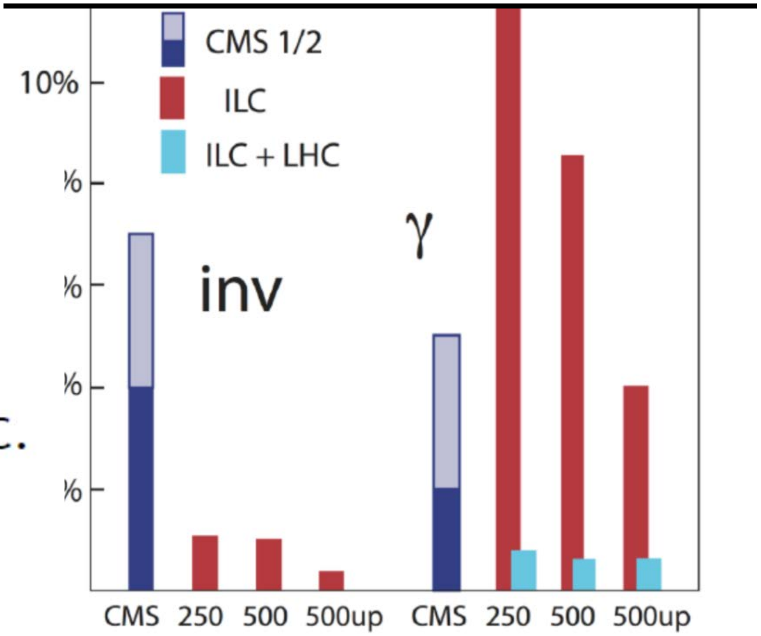


ATLAS estimates a measurement uncertainty

$$\Delta[BR(h \to \gamma\gamma)/BR(h \to ZZ^*)] \sim 2.9\%$$

free of theoretical systematics, from the HL-LHC.

Add this one data point to the Linear Collider measurements:



Light-on-light scattering at PLC

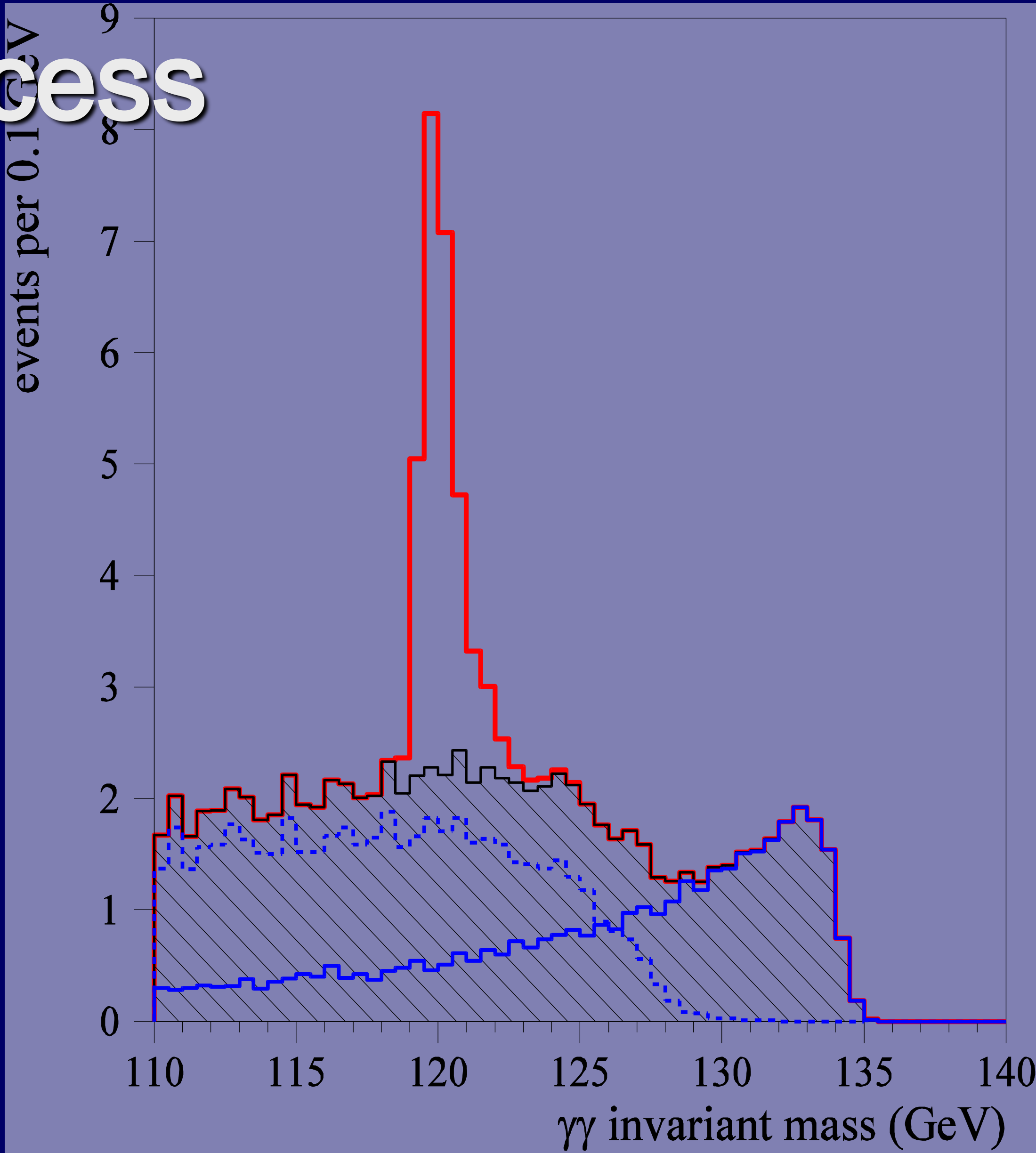
in SM loop process

SM-Higgs

γγ->h->γγ

(Velasco .. 2002)

-> Measures directly two-photon width of Higgs without assumptions about unobserved channels, couplings, etc

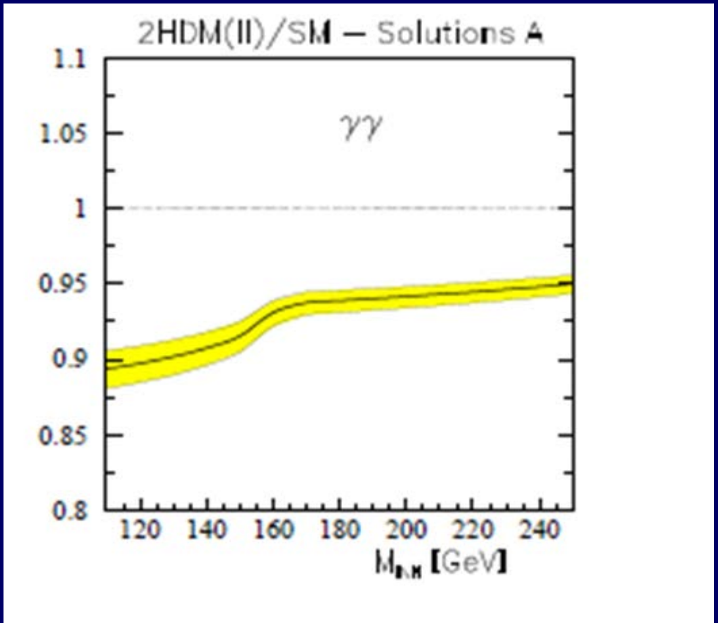


Neutral Higgs couples to photons via loops with charged particles

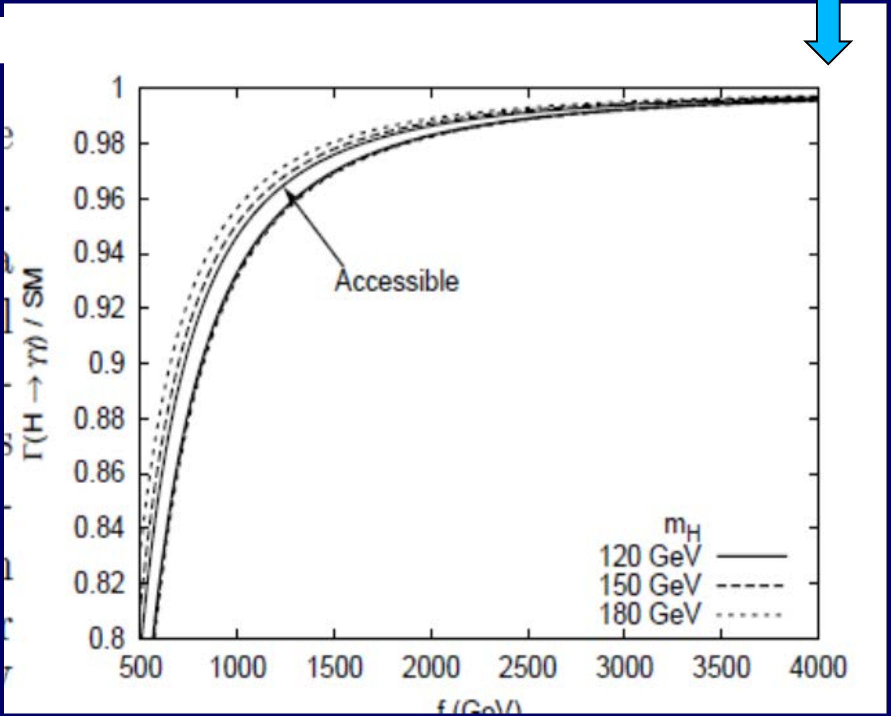
$H \to \gamma\gamma$ partial width is sensitive to the fundamental charged particles with very large masses

eg. 2HDM with Model II

(Ginzburg, MK, Osland 2001) t



Littlest Higgs model {Han ..]



Inert Doublet Model

Ma,…'78
Barbieri..'06

Symmetry under Z_2 transf. $\Phi_S \to \Phi_S \quad \Phi_D \to - \Phi_D$
both in L (V and Yukawa interaction = Model I only Φ_S)
and in the vacuum:

$<\Phi_S> = v \qquad <\Phi_D> = 0$ Inert vacuum I_1

Today

Φ_S as in SM (BEH), with Higgs boson h (SM-like)
Φ_D has <u>no vev</u>, with 4 scalars (no Higgs bosons!)
no interaction with fermions (inert doublet)

Here Z_2 symmetry exact $\to Z_2$ parity, only Φ_D has odd Z_2-parity
→ The lightest scalar stable -a dark matter candidate
(Φ_D dark doublet with dark scalars) .

$\Phi_1 \to \Phi_S$ Higgs doublet S $\qquad \Phi_2 \to \Phi_D$ Dark doublet D

The Inert Doublet Model: An Archetype for Dark Matter, Lopez Honorez,..Tytgat ..07

$h \to \gamma\gamma$

Świeżewska, MK (Dec. 2012)

[J. R. Ellis, M. K. Gaillard and D. V. Nanopoulos, Nucl. Phys. B 106 (1976) 292, M. A. Shifman, A. I. Vainshtein, M. B. Voloshin and V. I. Zakharov, Sov. J. Nucl. Phys. 30 (1979) 711 [Yad. Fiz. 30, 1368 (1979)], P. Posch, Phys. Lett. B696 (2011) 447, A. Arhrib, R. Benbrik, N. Gaur, Phys. Rev. D85 (2012) 095021]

$$R_{\gamma\gamma} = \frac{\sigma(pp \to h \to \gamma\gamma)^{IDM}}{\sigma(pp \to h \to \gamma\gamma)^{SM}} = \frac{\left(\sigma(gg \to h)\mathrm{Br}(h \to \gamma\gamma)\right)^{IDM}}{\left(\sigma(gg \to h)\mathrm{Br}(h \to \gamma\gamma)\right)^{SM}} = \frac{\mathrm{Br}(h \to \gamma\gamma)^{IDM}}{\mathrm{Br}(h \to \gamma\gamma)^{SM}}$$

- Narrow width approximation
- Largest contribution to the production is from gg fusion
- $\sigma(gg \to h)^{SM} = \sigma(gg \to h)^{IDM}$

Two sources of possible enhancement:

modification of the partial ($h \to \gamma\gamma$) or the total decay width ($h \to X$)

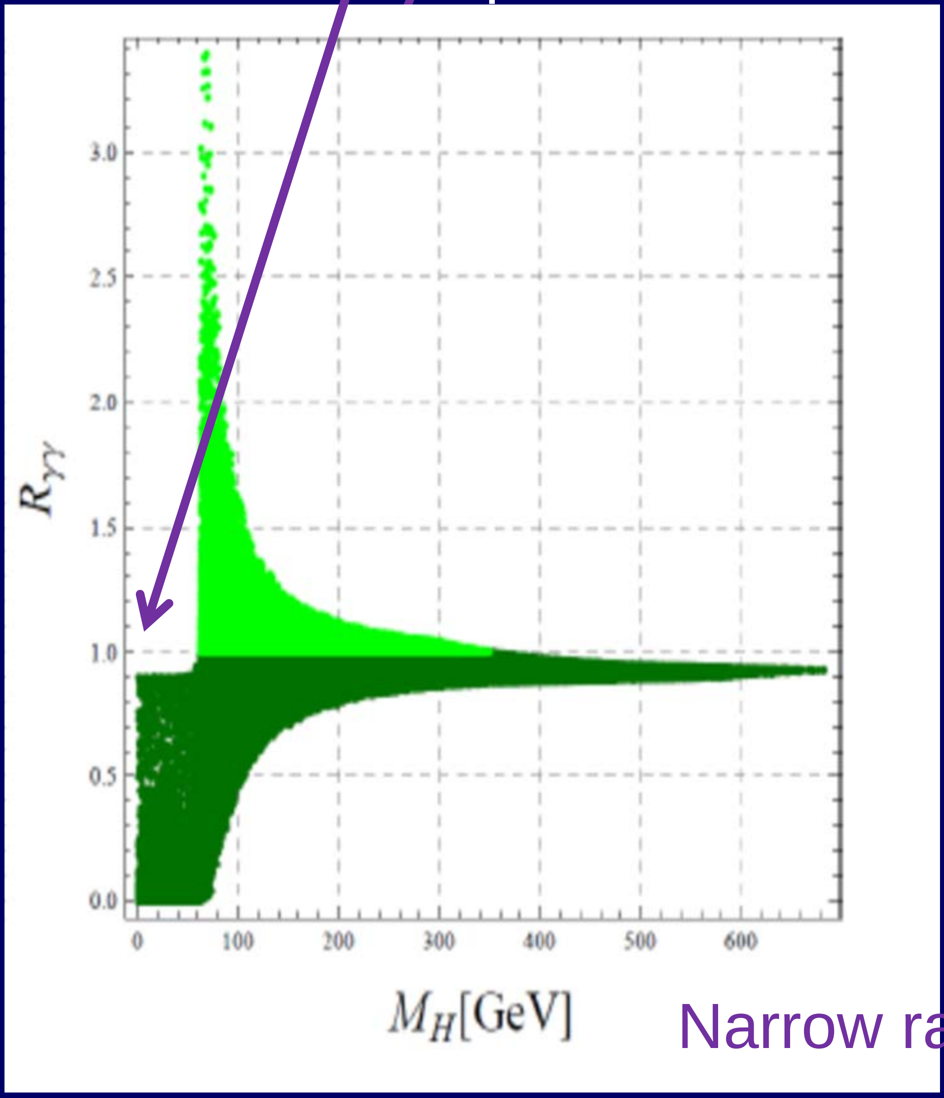
Sources of modifications to $R_{\gamma\gamma}$ - charged scalar loop

$$\Gamma(h \to \gamma\gamma)^{IDM} = \frac{G_F \alpha^2 M_h^3}{128\sqrt{2}\pi^3} \left| \frac{4}{3} g_t A_{1/2}\left(\frac{4M_t^2}{M_h^2}\right) + g_W A_1\left(\frac{4M_W^2}{M_h^2}\right) + \frac{2M_{H^\pm}^2 + m_{22}^2}{2M_{H^\pm}^2} A_0\left(\frac{4M_{H^\pm}^2}{M_h^2}\right) \right|^2$$

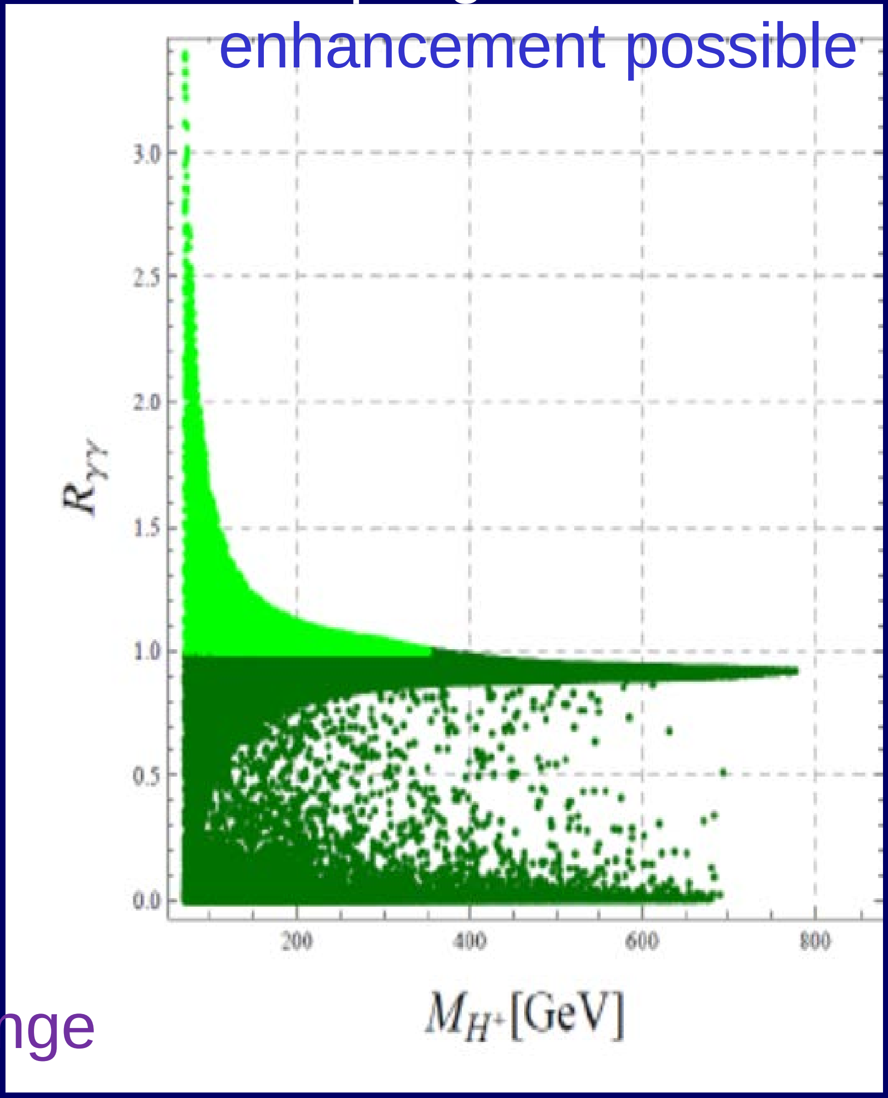
- If $h \to HH$ kinematically closed, $R_{\gamma\gamma} = \Gamma(h \to \gamma\gamma)^{IDM} / \Gamma(h \to \gamma\gamma)^{SM}$.
- $g_t, g_W = 1 \Rightarrow R_{\gamma\gamma}$ depends only on two of the parameters $M_{H^\pm}, \lambda_3, m_{22}^2$ $(M_{H^\pm}^2 = \frac{1}{2}(-m_{22}^2 + \lambda_3 v^2))$
- $R_{\gamma\gamma} > 1$ can be solved analytically -> formula
- enhancement in $h \to \gamma\gamma$ only possible for $m_{22}^2 < -9800\ \mathrm{GeV}^2$ $(\lambda_3 < 0)$

$R_{\gamma\gamma}$ as a function of mass H and H +

Invisible decays makes enhancement impossible

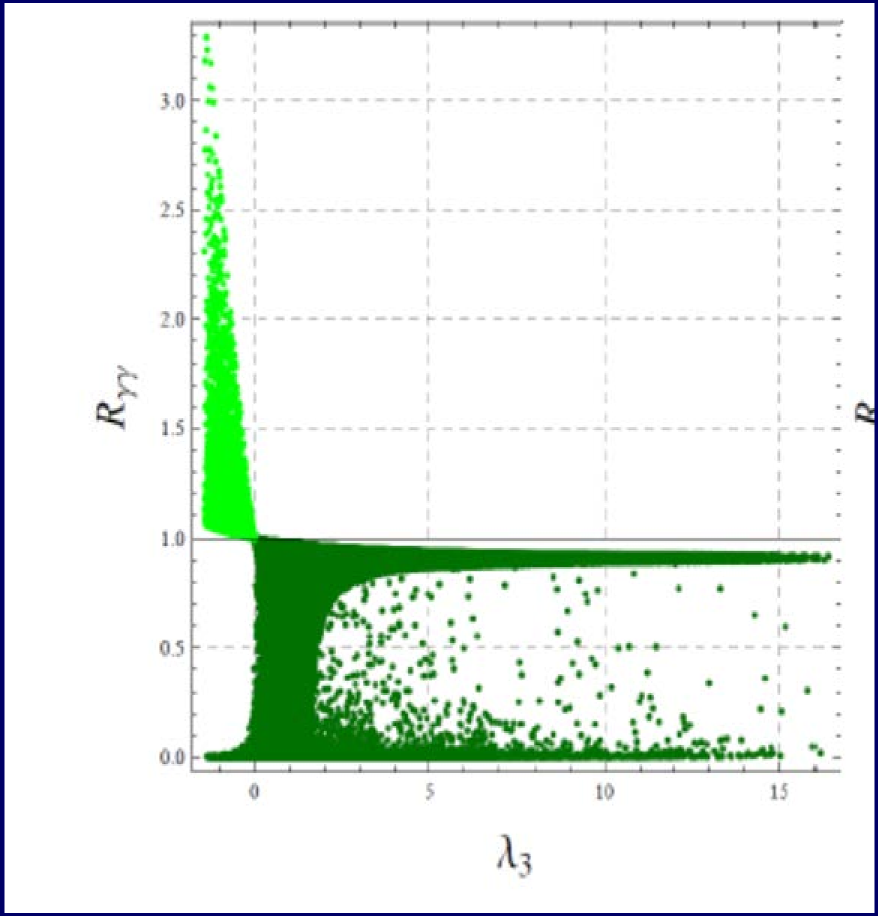


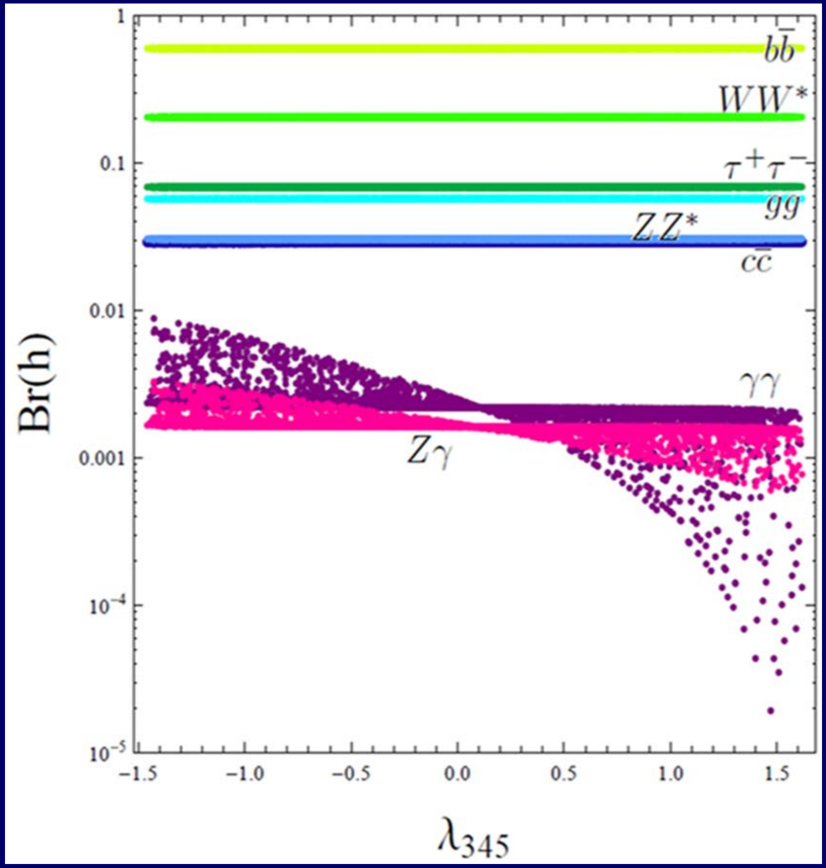
Light H+ with proper sign of hH+H- coupling makes enhancement possible



Narrow range

$R_{\gamma\gamma}$ as a function of λ_3





similar result
Arhrib at al

enhancement for negative λ_3

Constraining **Inert** Dark Matter by $R_{\gamma\gamma}$ and WMAP data

M. Krawczyk, D. Sokolowska, P. Swaczyna, B. Swiezewska

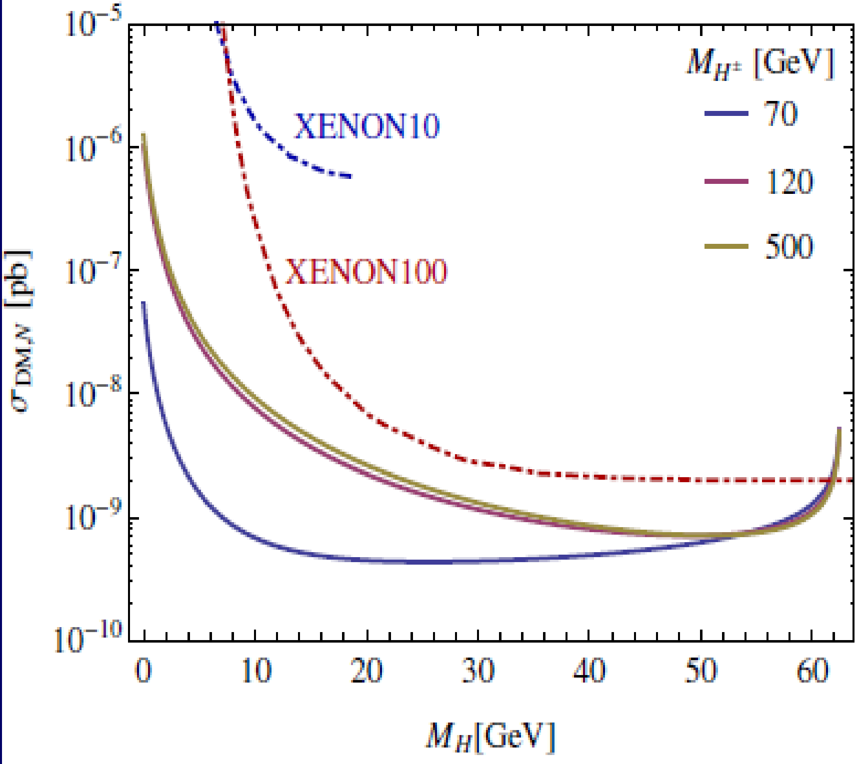
May 2013

Relict DM density

$$\Omega_{DM} h^2 = 0.1126 \pm 0.0036.$$

LHC data

$$\text{ATLAS} : R_{\gamma\gamma} = 1.65 \pm 0.24(\text{stat})^{+0.25}_{-0.18}(\text{syst}),$$
$$\text{CMS} : R_{\gamma\gamma} = 0.79^{+0.28}_{-0.26}.$$



(b) $R_{\gamma\gamma} > 0.8$

Stronger limit than Xenon100 !

$h \to AA$ channel is closed.

„Wrong” signs of fermion couplings

-> loop couplings ggh/H, γγh/H

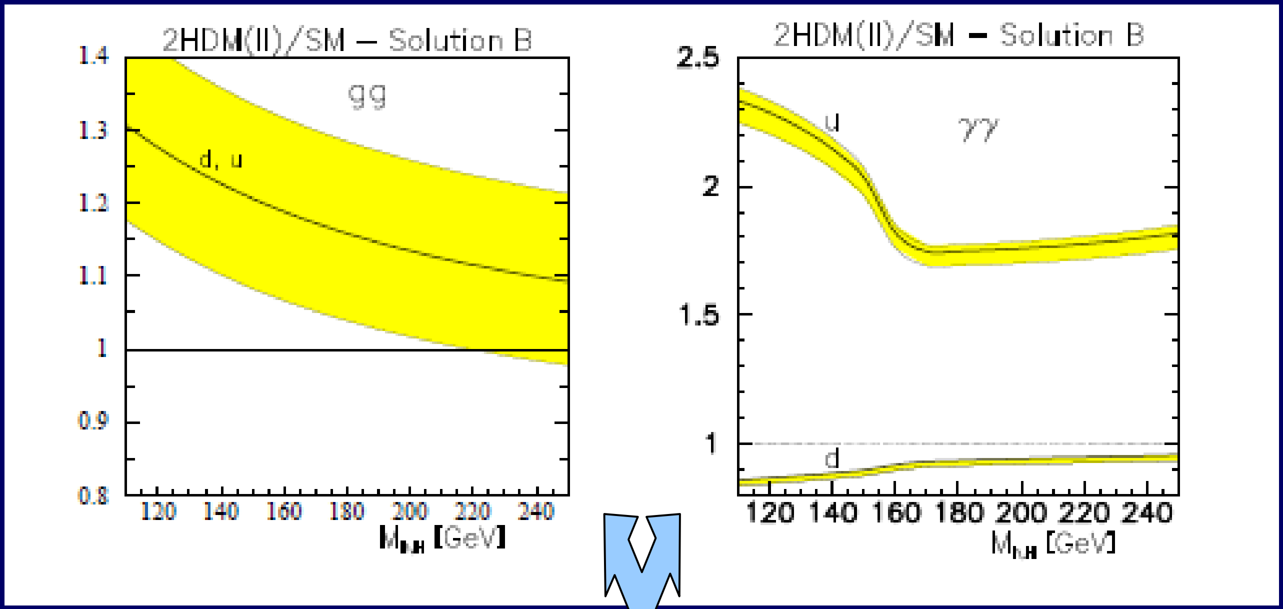
$\Gamma(h/H \to gg, \gamma\gamma)$

including exp. uncertainties

$2HDM(Z_2)$ = Mixed

Ginzburg,Osland, MK '2001

γγ



Both h and H maybe SM-like

Two solutions of pattern relation: LC-TH-2001-026

A – all couplings close to 1

B – one Yukawa coupling close to -1

Loop induced couplings gg, $\gamma\gamma$, $Z\gamma$ different for A and B

MH+=600 GeV

For h or H with mass 120 GeV

solution	basic couplings	$\lvert\chi_{gg}\rvert^2$	$\lvert\chi_{\gamma\gamma}\rvert^2$	$\lvert\chi_{Z\gamma}\rvert^2$
A_{h+}/A_{H-}	$\chi_V \approx \chi_d \approx \chi_u \approx \pm 1$	1.00	0.90	0.96
B_{h+d}/B_{H-d}	$\chi_V \approx -\chi_d \approx \chi_u \approx \pm 1$	1.28	0.87	0.96
$B_{h\pm u}$	$\chi_V \approx \chi_d \approx -\chi_u \approx \pm 1$	1.28	2.28	1.21

„wrong" sign of coupling to top →
large enhancement of hgg, $h\gamma\gamma$, $hZ\gamma$! and Hgg

Higgs selfcoupling

- In the SM this selfcoupling is precisely fixed via Higgs mass (and v.e.v. v = 246 GeV), while deviations from it's SM value would be a clear signal of more complex Higgs sector.

  Two neutral Higgs bosons are produced in processes both with and without selfnteraction

$e^+e^- \rightarrow Z \rightarrow H(Z \rightarrow ZH) \oplus e^+e \rightarrow Z \rightarrow Z(H \rightarrow HH)$;

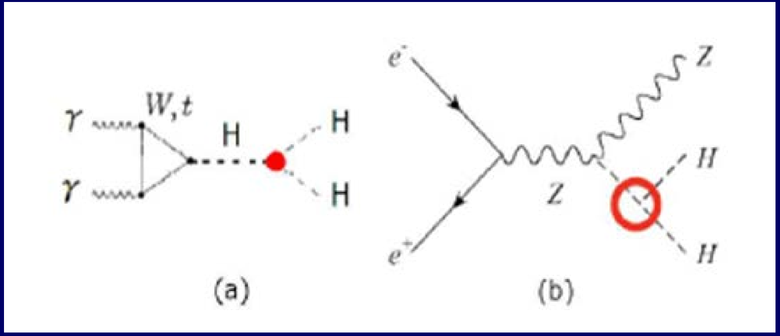
$\gamma\gamma \rightarrow \text{loop} \rightarrow HH \oplus \gamma\gamma \rightarrow \text{loop} \rightarrow H \rightarrow HH$

A feasibility study of the measurement of Higgs pair creation at a Photon Linear Collider

May 2012

Shin-ichi Kawada[1],* Nozomi Maeda[1], Tohru Takahashi[1], Katsumasa Ikematsu[2], Keisuke Fujii[3], Yoshimasa Kurihara[3], Koji Tsumura[4], Daisuke Harada[5], and Shinya Kanemura[6]

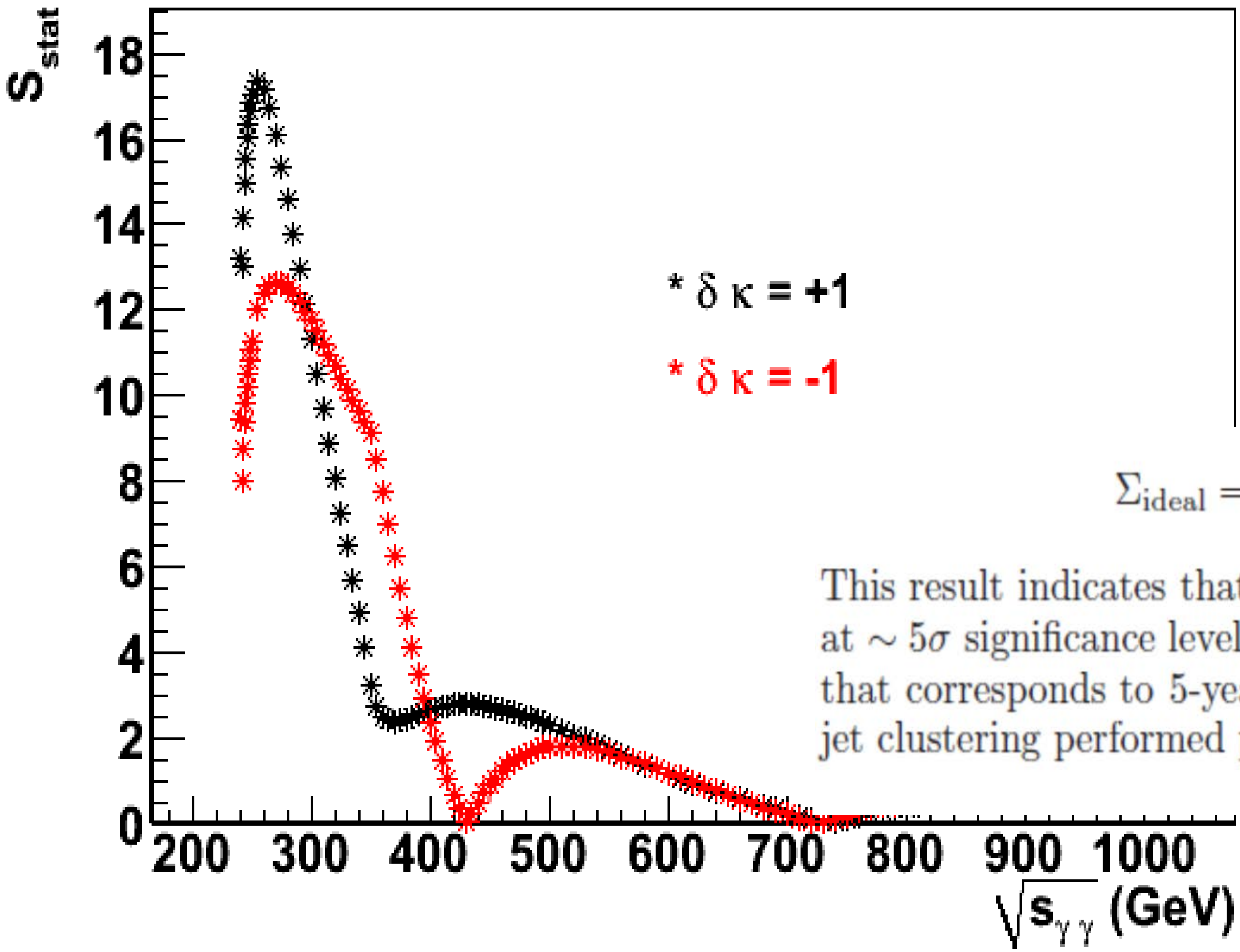
- From the sensitivity to the anomalous selfcoupling of the Higgs boson, the optimum γγ collision energy was found ~ 270 GeV for a Higgs mass of 120 GeV
- Large backgrounds γγ→WW,ZZ , bb can be suppressed if correct assignment of tracks to parent partons is achieved and Higgs pair events can be observed with statistical significance of ~5σ by operating the PLC for 5 y



Earlier study Jikia, Beluscovic, Asakawa at al., Cornet et al..

Stat.sensitivity

$$\lambda = \lambda^{\rm SM}(1 + \delta\kappa),$$



$$S_{\rm stat} = \sqrt{L}\frac{|\sigma(\delta\kappa) - \sigma_{\rm SM}|}{\sqrt{\sigma(\delta\kappa)}}.$$

$$\Sigma_{\rm ideal} = 4.87 \pm 0.13\sigma. \qquad (7)$$

This result indicates that $\gamma\gamma \to HH$ would be observed at $\sim 5\sigma$ significance level with the integrated luminosity that corresponds to 5-year operation of the PLC, if the jet clustering performed perfectly.

$\sqrt{s_{\gamma\gamma}} \approx 270$ GeV

e+e- 44 % integra. luminosity of 2 ab-1 at 500 GeV

Studies of heavier Higgses, for 125 GeV $\mathcal{H} = h(1)$

A single Higgs production at *γγ* collider allows to explore roughly the same mass region for neutral Higgs bosons at the parent *e+e-* LC but with higher cross section and lower background.

The *eγ* collider allows in principle to test wider mass region in the process $e\gamma \to eH, eA$ however with a lower cross section.

Sum rules

For an arbitrary Yukawa interaction there are sum rules for coupling of dierent neutral Higgses to gauge bosons *V = W, Z* and to each separate fermion *f* (quark or lepton). In 2HDM (Haber,Wodka)

$$\sum_{i=1}^{3}(\chi_V^{(i)})^2 = 1\,. \qquad \sum_{i=1}^{3}(\chi_f^{(i)})^2 = 1\,.$$

In the 2HDM (II) following relations hold:

The pattern relation among the relative couplings for *each neutral Higgs particle*

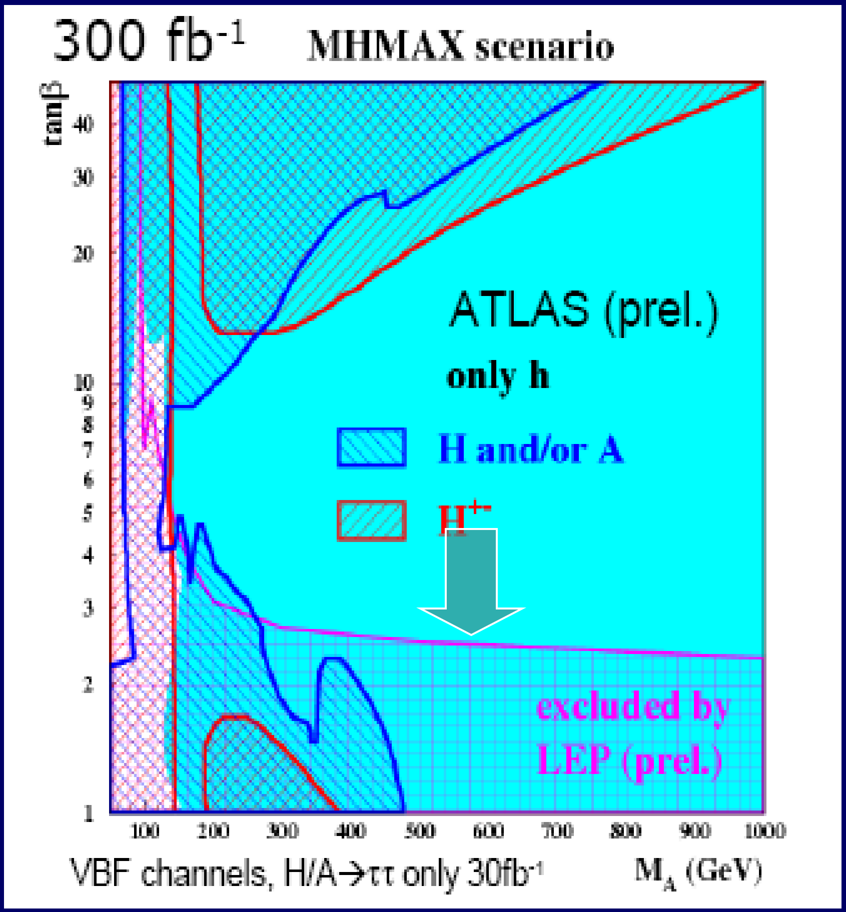
$$(\chi_u^{(i)} + \chi_d^{(i)})\chi_V^{(i)} = 1 + \chi_u^{(i)}\chi_d^{(i)}\,.$$

For each neutral Higgs boson *h*(*i*) a horizontal sum rule

$$|\chi_u^{(i)}|^2 \sin^2\beta + |\chi_d^{(i)}|^2 \cos^2\beta = 1\,.$$

(Gunion, Haber, Kalinowski,)

MSSM Higgs searches/overall discovery potential (300 fb^{-1}) at LHC



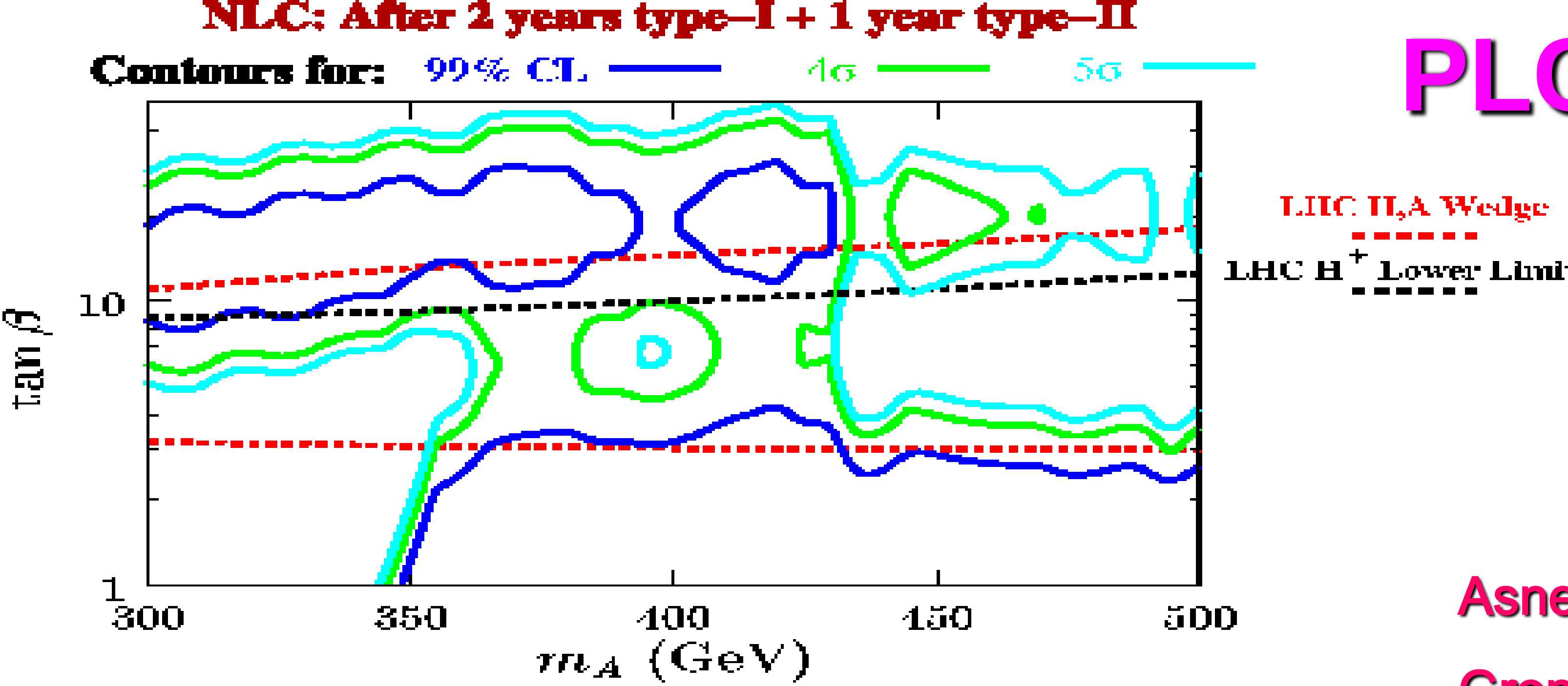
- in some parts >1 Higgs bosons observable
- but large area in which only one Higgs boson h (SM-like) observable

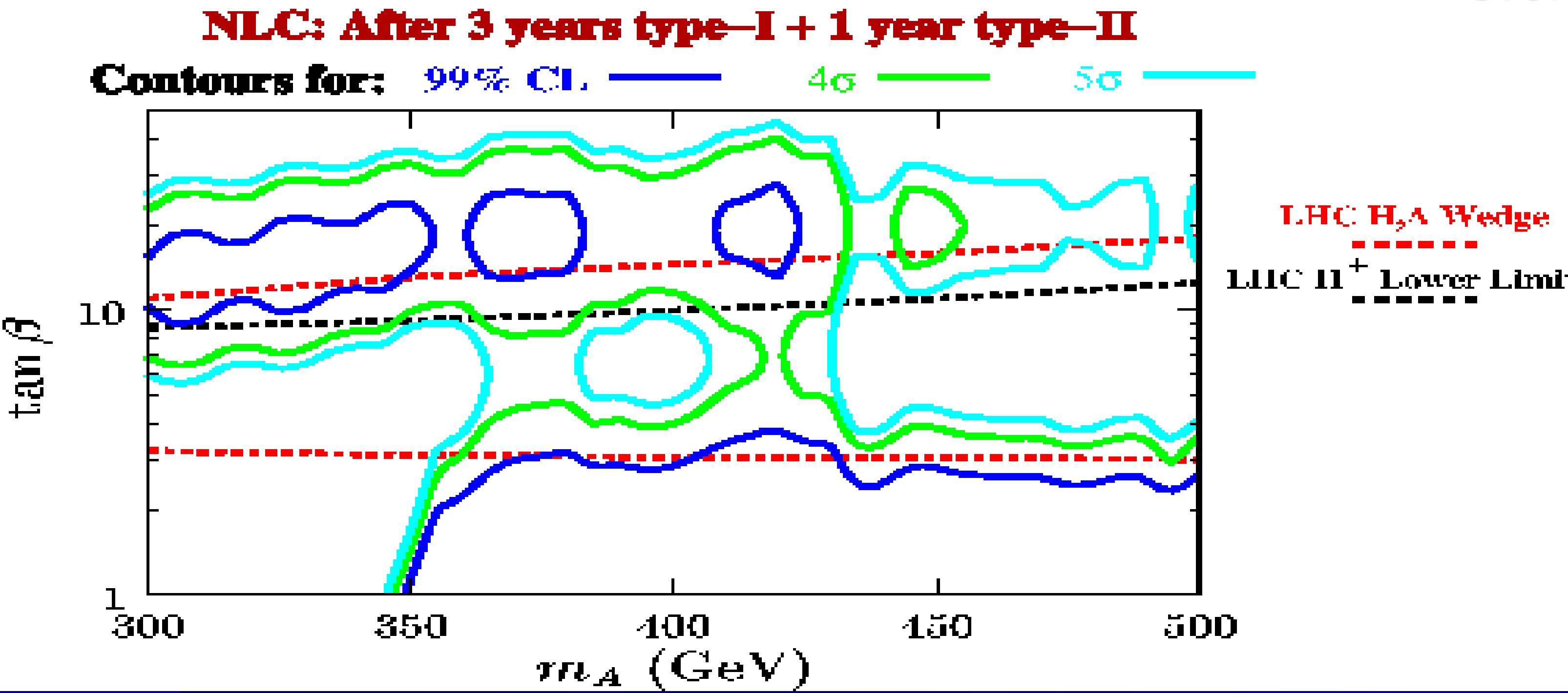
LHC wedge

Basic question: Could we distinguish SM and MSSM Higgs sector
- e.g via rate measurements?

heavy A and H degenerate

PLC





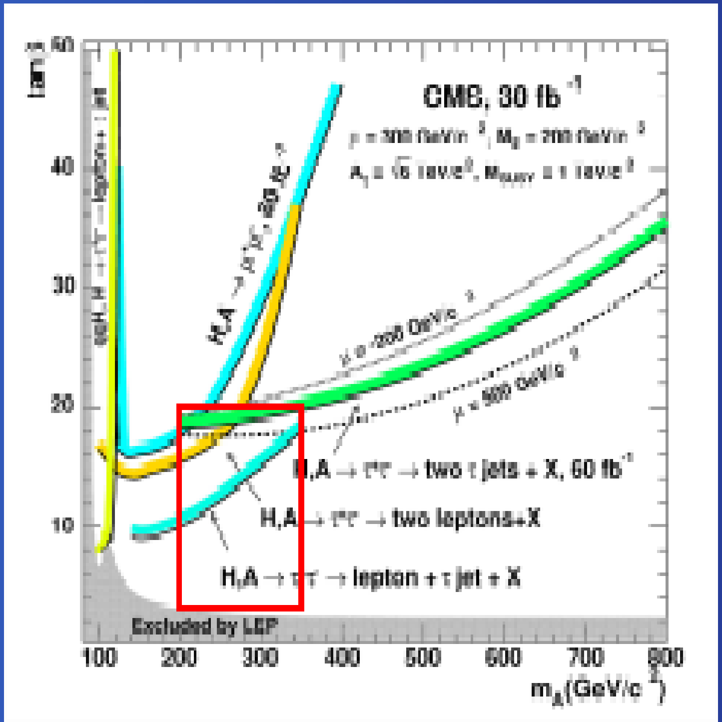
Asner, Gunion, Gronberg 2001

Niezurawski et al..

MSSM: LHC wedge at PLC

NŻK

LHC wedge



From: CMS NOTE 2003/033
(the same results as in newer CMS CR 2004/058)

We consider four MSSM parameter sets:

Symbol	μ [GeV]	M_2 [GeV]	$A_{\tilde{t}}$ [GeV]
I	200	200	1500
II	-150	200	1500
III	-200	200	1500
IV	300	200	2450

I and III – as in M. Mühlleitner *et al.*
with higher $A_{\tilde{t}}$ to have M_h above 114 GeV

II – an intermediate scenario

IV – as in CMS NOTE 2003/033

MSSM: Precision at PLC

NŻK

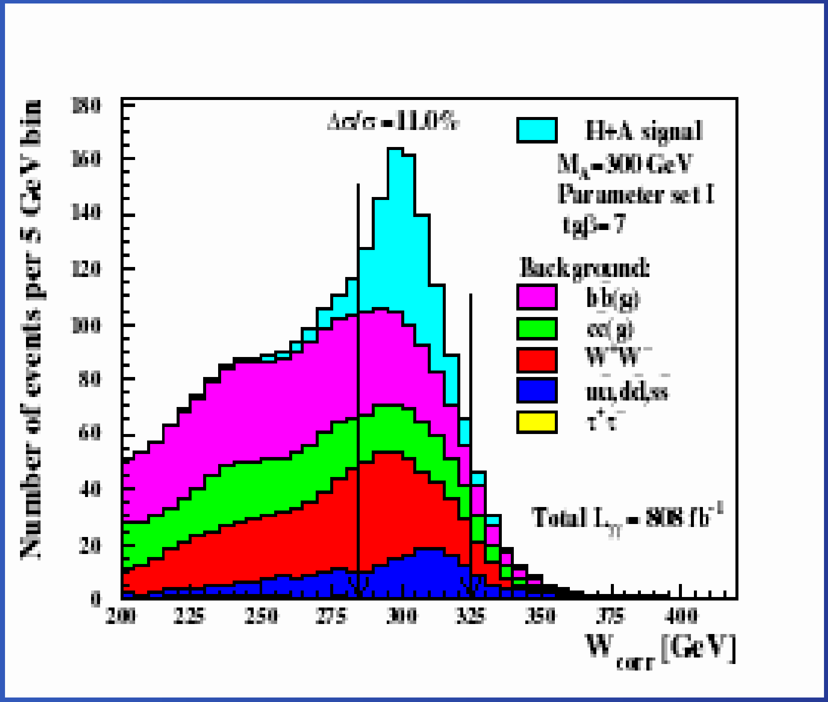
Spira et al

Niezurawski et al.,- simulation

Covering the LHC wedge at PLC

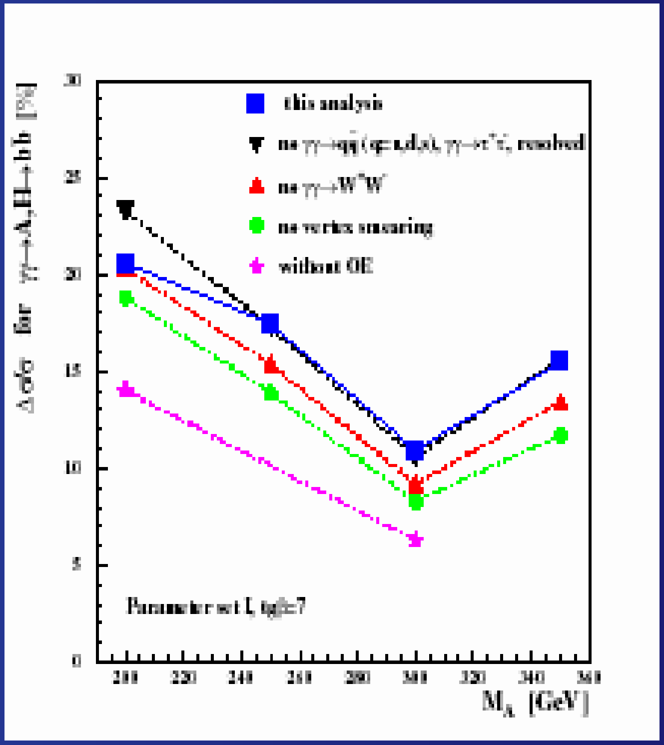
Precision of $\sigma(\gamma\gamma \to A, H \to b\bar{b})$ mesurement

Results for $M_A = 300$ GeV



Corrected invariant mass distributions

Results for $M_A = 200$-350 GeV



our previous results compared

Using lin.polarisation -> A,H separation

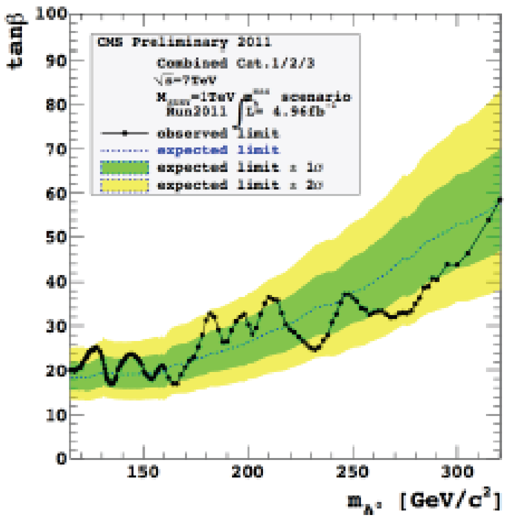
MSSM

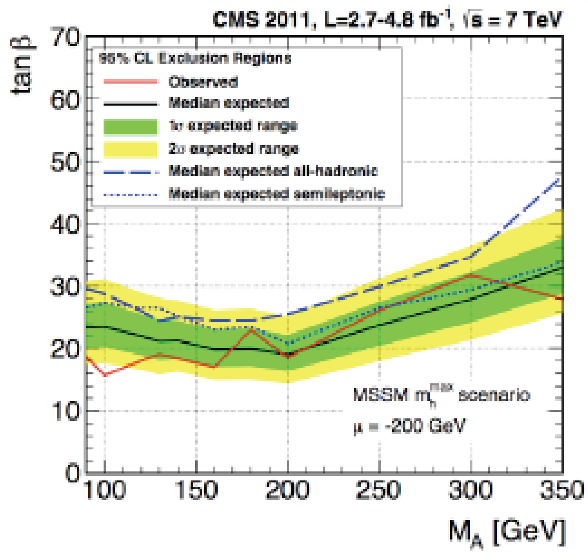
channel: μμ
- even with a BR of ≈10^{-4} good sensitivity is achieved
- best channel for a precise measurement of tanβ

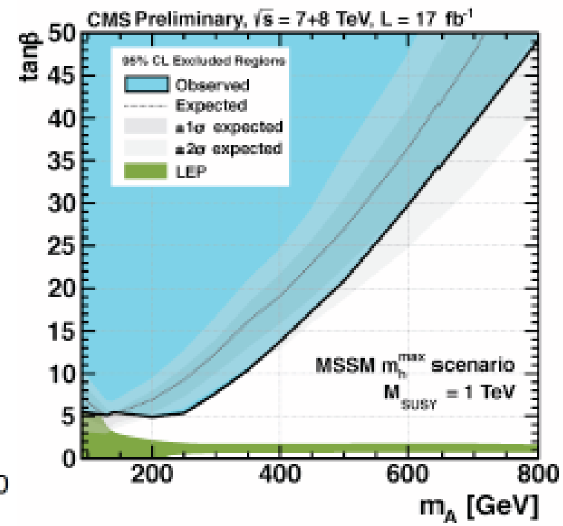
CMS PAS HIG-12-011

channel: bb
- good BR
- challenging background
- more details in **arXiv:1302.2892**

channel: ττ
- better background conditions and ditau mass parameterization
- **CMS PAS HIG-12-050**







- there is an ongoing effort in CMS to combine all analyses and complete the analysis of the √s = 8 TeV data (plan to be ready during summer)

MSSM

channel: μμ
- even with a BR of ≈10^{-4} good sensitivity is achieved
- best channel for a precise measurement of tanβ

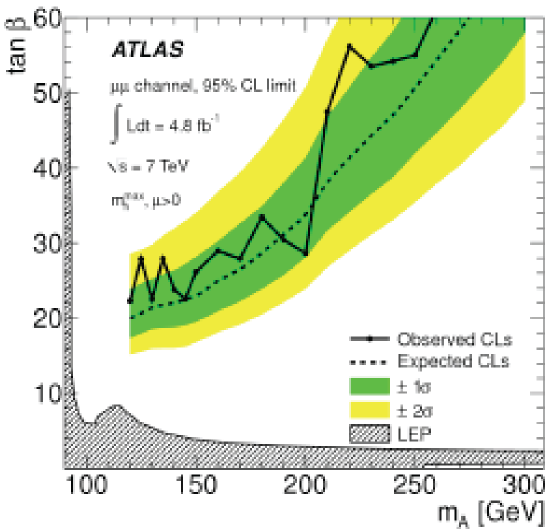
arXiv:1211.6956

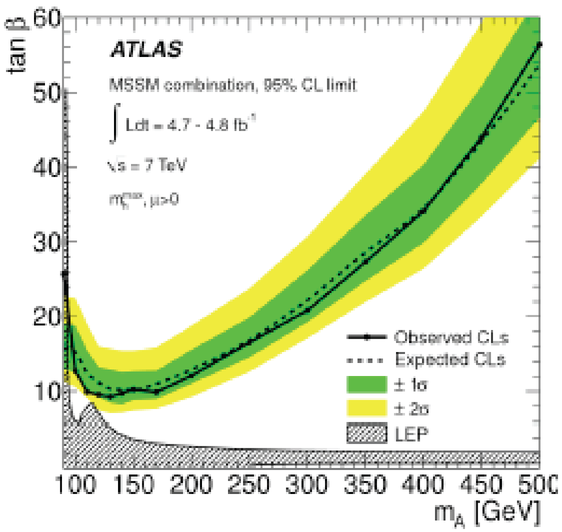
channel: ττ
- better background conditions and ditau mass parameterization

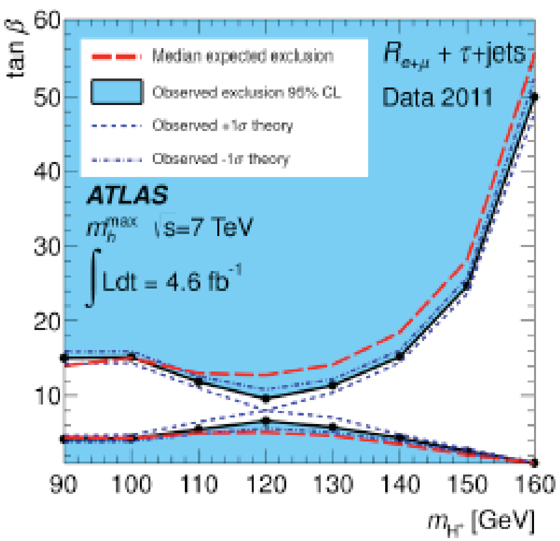
arXiv:1211.6956

Charged Higgs: $H^+ \to \tau^+ \nu_\tau$
- with the Higgs boson produced via $t \to H^+ b$

arXiv:1212.3572







PLC – the best for CP study

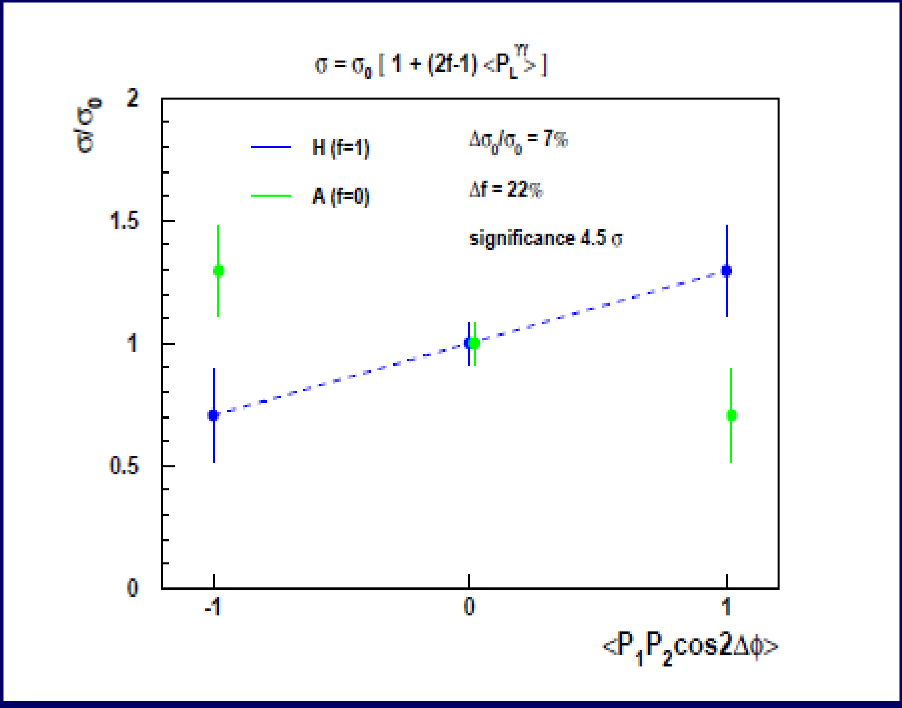
PLC provides the best for the study of spin and the CP properties of heavy *Higgses.* That are CP parity in the CP conserved case (*H, A*), and (complex) degree of the admixtures of states (h2,h3) with diferent CP parity, if CP is violated.

This admixture determines dependence on the Higgs production cross section on direction of incident photon polarization.

Degenerated heavy Higgses

Polarization measurements are useful in the study of the case when the heavy states *h*(2), *h*(3) (*H, A*) are degenerated in their masses. A study by Zarnecki shows that the 3-years run PLC with linear polarization of photons, the production of *H* and *A (with mass 300 GeV)* corresponding to LHC wedge can be separately measured with precison 20%.

Pure scalar versus pure pseudoscalar states can be distinguished at 4.5 *σ* level.



The *CP* mixed and the mass-degenerate states

Degeneracy of some resonances *A* and *B:*

a) instrumental degeneracy when

$$|M_B - M_A| > \Gamma_B + \Gamma_A,$$

with mass diference within a mass resolution of detector. This effect can be resolved with improving of a resolution of the detector

b) physical degeneracy when $|M_B - M_A| < \Gamma_B + \Gamma_A.$

Note, that in the CP violating case, the overlapping of resonances results in additional mixing of incident $h_{(2)}$, $h_{(3)}$ states, and the production cross-section varies with the change of polarization direction of incident photons.

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

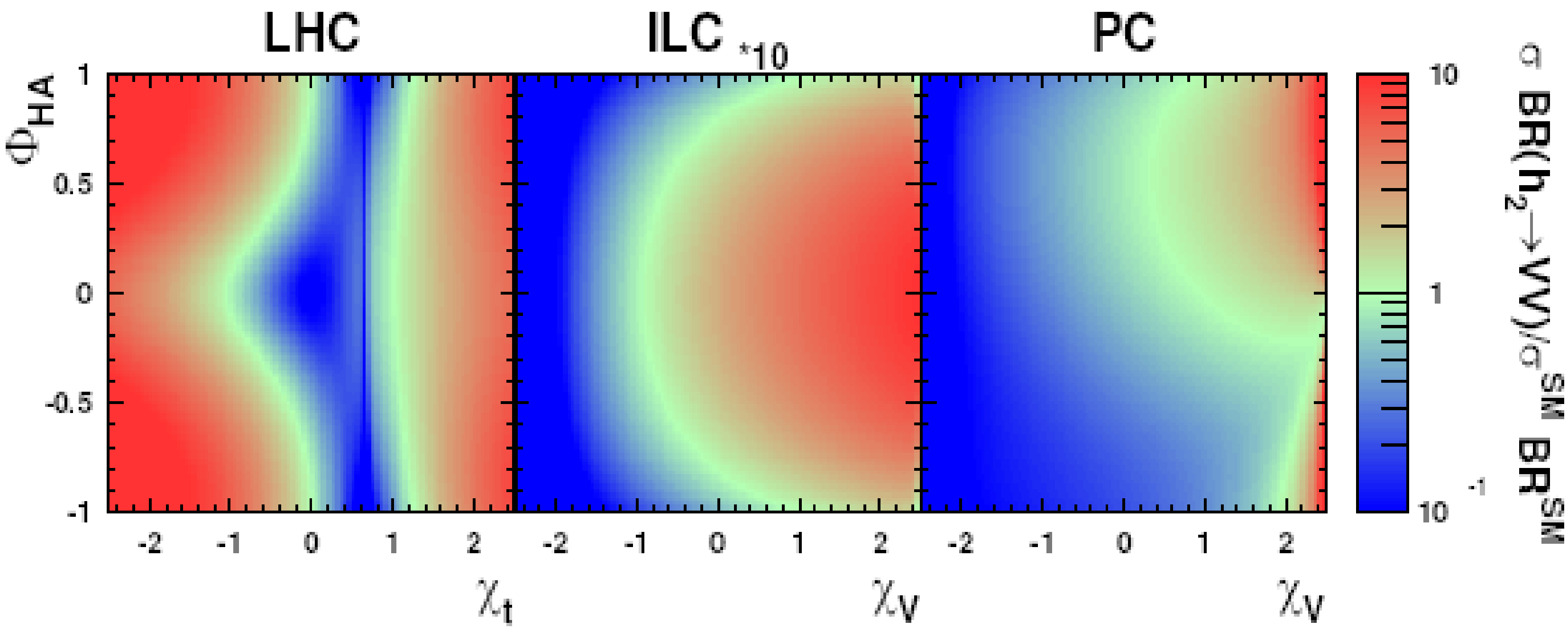
We consider h_2 production and decays, for $|\Phi_{HA}| \ll 1$ (weak CP violaion)

Zarnecki, Niezurawski, MK

LHC $\oplus$ ILC $\oplus$ PC

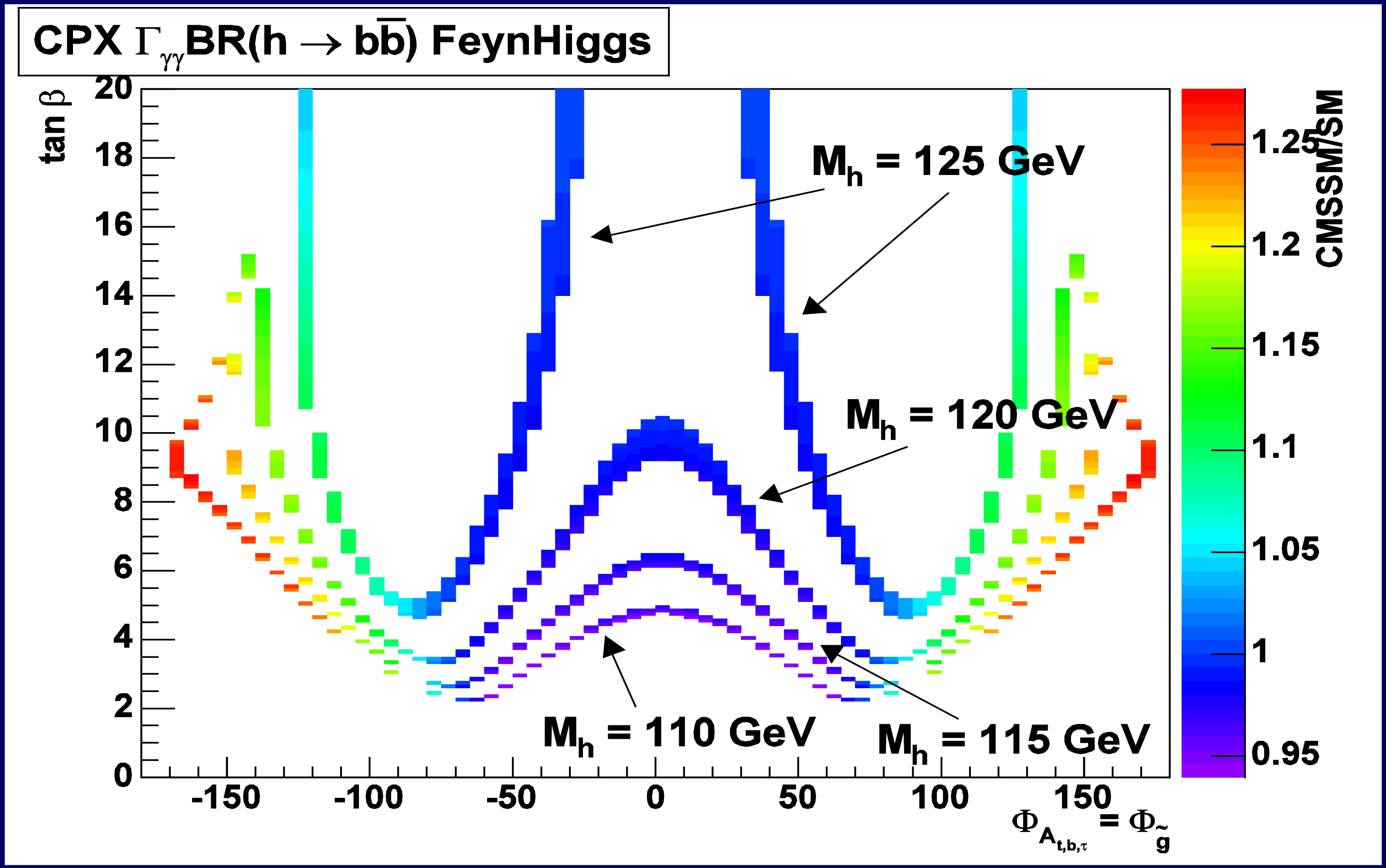
Sensitivity of LHC, ILC and Photon Collider measurements to CP-violating mixing phase Φ_{HA}

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



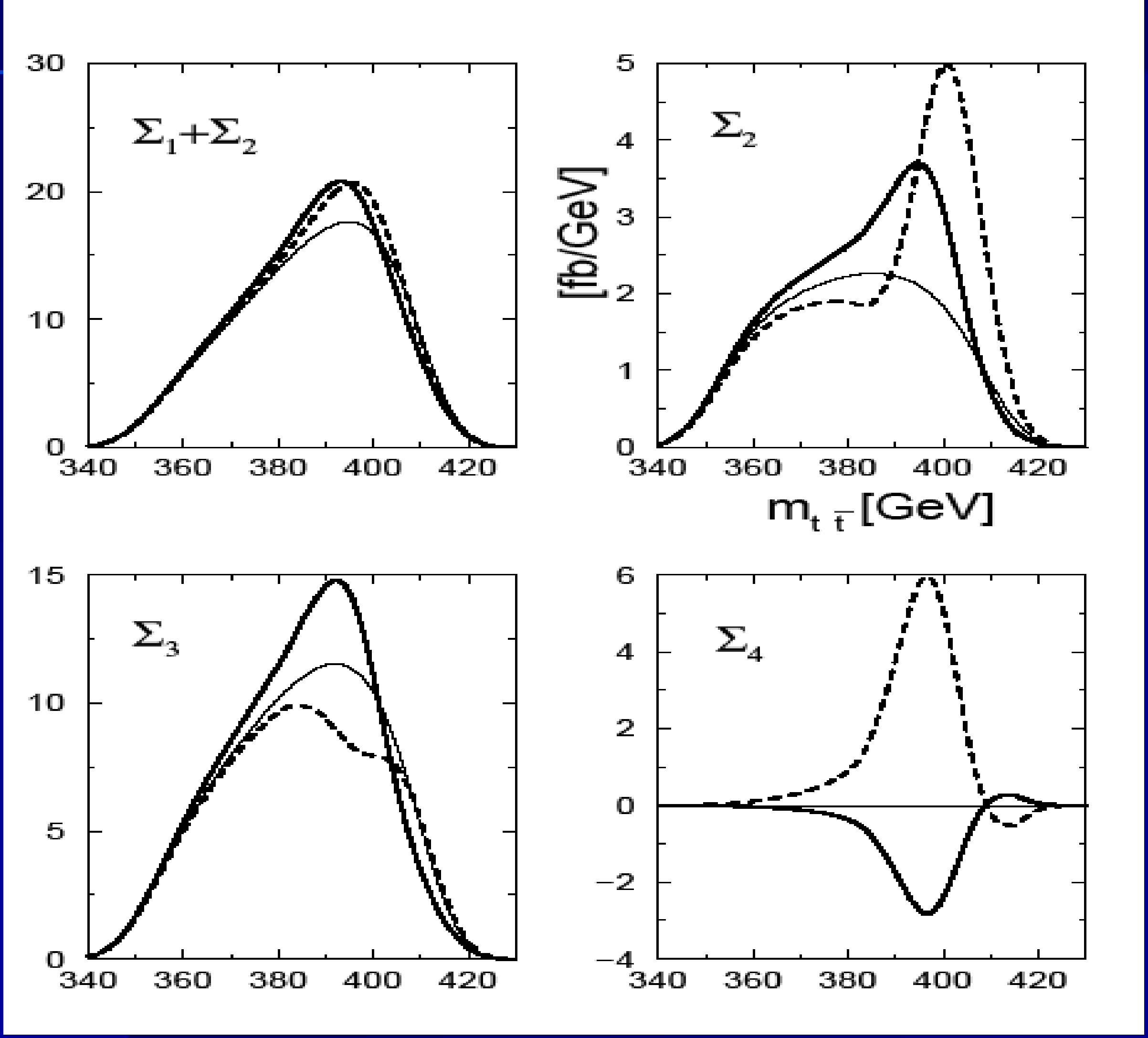
CPX scenario (max CP violation in CMSSM) studied for LHC, ILC, PLC (CLIC ?)

by Heinemeyer, Velasco 2004



CP-even, CP-odd states in $\gamma\gamma \rightarrow t\,t$

Asakawa, .. 2000



Scalar (dashed)

Pseudoscalar (thick)

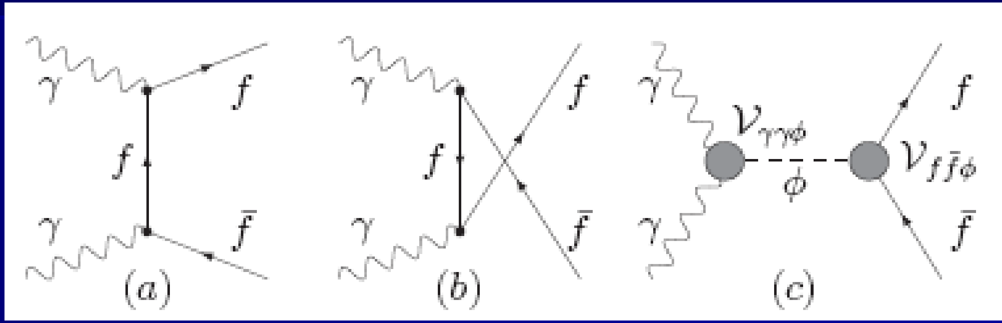
Mass – 400 GeV

Probing the CP-violating Higgs contribution in $\gamma\gamma \rightarrow$ ff

Godbole, Kraml, Rindani, Singh 2006

- For f = top, tau
- Using fermion polarization

to construct various asymmetries



- Both for CP conserving and CP violating case
- Model independent analysis and in addition

CPX scenario (MSSM) – for light Higgs numerical analysis

$$\phi f \bar{f} \; : \; \frac{-ig\, m_f}{2\, M_W} \left(v_f + i a_f \gamma_5 \right) \quad (1)$$

$$\phi VV \; : \; \frac{ig\, M_V^2}{M_W} \left(A_V\, g_{\mu\nu} + B_V \frac{p_\mu p_\nu}{M_Z^2} + i\, C_V \epsilon_{\mu\nu\rho\sigma} \frac{p^\rho q^\sigma}{M_Z^2} \right) \quad (2)$$

ff democratic CP-even and CP-odd coupling

In contrast to VV case – typically A_V dominates

H+ production at PLC

Discovery of H+ = BSM physics

H+H- in $\gamma\gamma$ and e+e- produced in QED processes

Also H+H- h and H+H-H, H+H- A possible – sensitive to H+H-h coupling

Measurements in $\gamma\gamma$ preferable – higher cross sections and opportunity of using polarization

Testing Higgs sector at PLC

Precision measurements of the light Higgs boson production   (->bb) and distinguishing SM-like scenarios

Testing Higgs selfinteraction

Higher mass reach (covering LHC wedge)

Establishing CP property of Higgs bosons

Complementarity to ILC and LHC

Remark on Photon collider Higgs factories

Photon collider can measure $\Gamma(H\to\gamma\gamma)*Br(H\to bb, ZZ, WW)$, $\Gamma^2(H\to\gamma\gamma)/\Gamma_{tot}$, CP properties (using photon polarizations). In order to get $\Gamma(H\to\gamma\gamma)$ one needs $Br(H\to bb)$ from e+e-. This gives also Γ_{tot}.

e+e- can also measure Br(bb, cc, gg, ττ, μμ, invisible), Γ_{tot}, less backgrounds due to tagging of Z.

Therefore PLC is nicely motivated in combination with e+e-: parallel work or second stage.

A. de Roeck

Golden processes	PLC2000 proc.
$\gamma\gamma \to H, h \to b\bar{b}$	SM/MSSM Higgs, $M_{H,h} < 160$ GeV
$\gamma\gamma \to H \to WW(^*)$	SM Higgs, 140$< M_H <$ 190 GeV
$\gamma\gamma \to H \to ZZ(^*)$	SM Higgs, 180$< M_H <$ 350 GeV
$\gamma\gamma \to H \to \gamma\gamma$	SM Higgs, 120$< M_H <$ 160 GeV
$\gamma\gamma \to H \to t\bar{t}$	SM Higgs, $M_H >$ 350 GeV
$\gamma\gamma \to H, A \to b\bar{b}$	MSSM heavy Higgs, interm. $\tan\beta$
$\gamma\gamma \to H^+H^-$	large cross sections
$\gamma\gamma \to \tilde{f}\bar{\tilde{f}},\ \tilde{\chi}_i^+\tilde{\chi}_i^-$	large cross sections
$\gamma\gamma \to \tilde{g}\tilde{g}$	measurable cross sections
$\gamma\gamma \to S[\tilde{t}\bar{\tilde{t}}]$	$\tilde{t}\bar{\tilde{t}}$ stoponium
$\gamma e \to \tilde{e}^-\tilde{\chi}_1^0$	$M_{\tilde{e}^-} < 0.9 \times 2E_0 - M_{\tilde{\chi}_1^0}$
$\gamma\gamma \to \gamma\gamma$	non-commutative theories
$e\gamma \to eG$	extra dimensions
$\gamma\gamma \to \phi$	Radions
$e\gamma \to \tilde{e}\tilde{G}$	superlight gravitions
$\gamma\gamma \to W^+W^-$	anom. W inter., extra dimensions
$\gamma e \to W^-\nu_e$	anom.W couplings
$\gamma\gamma \to 4W/(Z)$	WW scatt., quartic anom. W,Z
$\gamma\gamma \to t\bar{t}$	anomalous top quark interactions
$\gamma e \to \bar{t}b\nu_e$	anomalous Wtb coupling
$\gamma\gamma \to$ hadrons	total $\gamma\gamma$ cross section
$\gamma e \to e^-X,\ \nu_eX$	NC and CC structure functions
$\gamma g \to q\bar{q},\ c\bar{c}$	gluon in the photon
$\gamma\gamma \to J/\psi\, J/\psi$	QCD Pomeron

Higgs Study – CP conservation

- SM CP even Higgs
- 2HDM: 5 Higgses, H+,H-; h,H,(CP-even) A (CP-odd); A no coupling to W/Z; sum rules for couplings

  -the lightest h can be SM-like

  (decoupling or non-decoupling of heavy Higgses)

  -the lightest h can be very light below say 50 GeV

  (with suppressed coupling to W/Z) → H is SM-like

  - the lightest can be A

  -Model II → mass of H+ above 350 GeV (b->s gam)
- MSSM (CP conserv, Model II): h- SM like (decoupling, degenerate H,A,H+; H with suppressed coupling to W/Z !!)

Higgs Study – CP violation

- 2HDM – neutral Higgses have no definite CP properties h1,h2,h3; all couple to W/Z
- CP-MSSM – very light h1 is allowed by LEP