Photon Linear Collider - or the fusion of light

ILC

Florence, September 2007

General overview
LHC-ILC-PLC synergy
Outlook

Maria Krawczyk
University of Warsaw

International Linear Collider Workshops

Accelerator Physics

Year	Workshop	Location
1988	LC88	SLAC
1990	LC90	KEK
1991	LC91	Protvino
1992	LC92	Garmisch
1993	LC93	SLAC
1995	LC95	KEK
1997	LC97	BINP, Zvenigorod
1999	LC99	INFN, Frascati
2002	LC02	SLAC
2004	1st ILC Workshop	KEK
2005	2nd ILC Workshop	Snowmass

3/9-12/06

Particle Physics

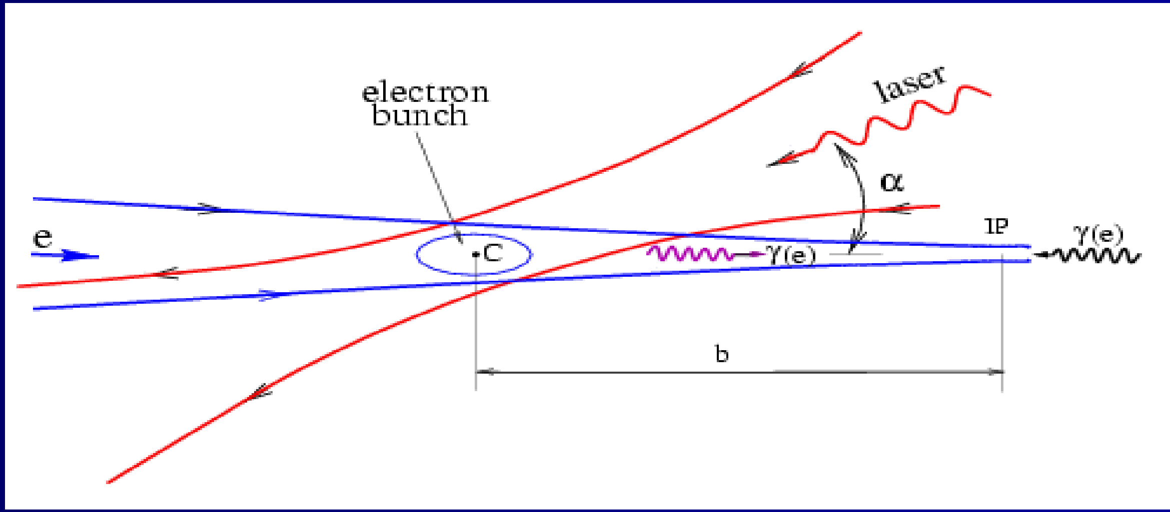
Year	Workshop	Location
1991	LCWS91	Saariselkä, Finland
1993	LCWS93	Waikoloa, HI
1995	LCWS95	Morioka-Appi, Japan
1999	LCWS99	Sitges, Barcelona, Spain
2000	LCWS00 **PLC2000**	Fermilab Batavia, IL USA
2002	LCWS02 **PLC2001**	Jeju, Korea
2004	LCWS04	Paris, France
2005	LCWS05 **PLC2005**	Stanford, USA
2006	LCWS06	Bangalore, India

LCWS2007–DESY

PHOTON2007-Paris

G. A. Loew, SLAC

Backward Compton Scattering- basic idea of the photon collider
Ginzburg, Telnov '85



- PLC - $\gamma\ \gamma$ and e γ options

The Photon Collider – main characteristics

- Variable energy and degree of polarization of the photon beams – both circular and linear – however (almost) monochromatic spectrum possible (a high energy peak)
- Clean or dirty collider? Hadronic interaction of photon ……

PLC at ILC

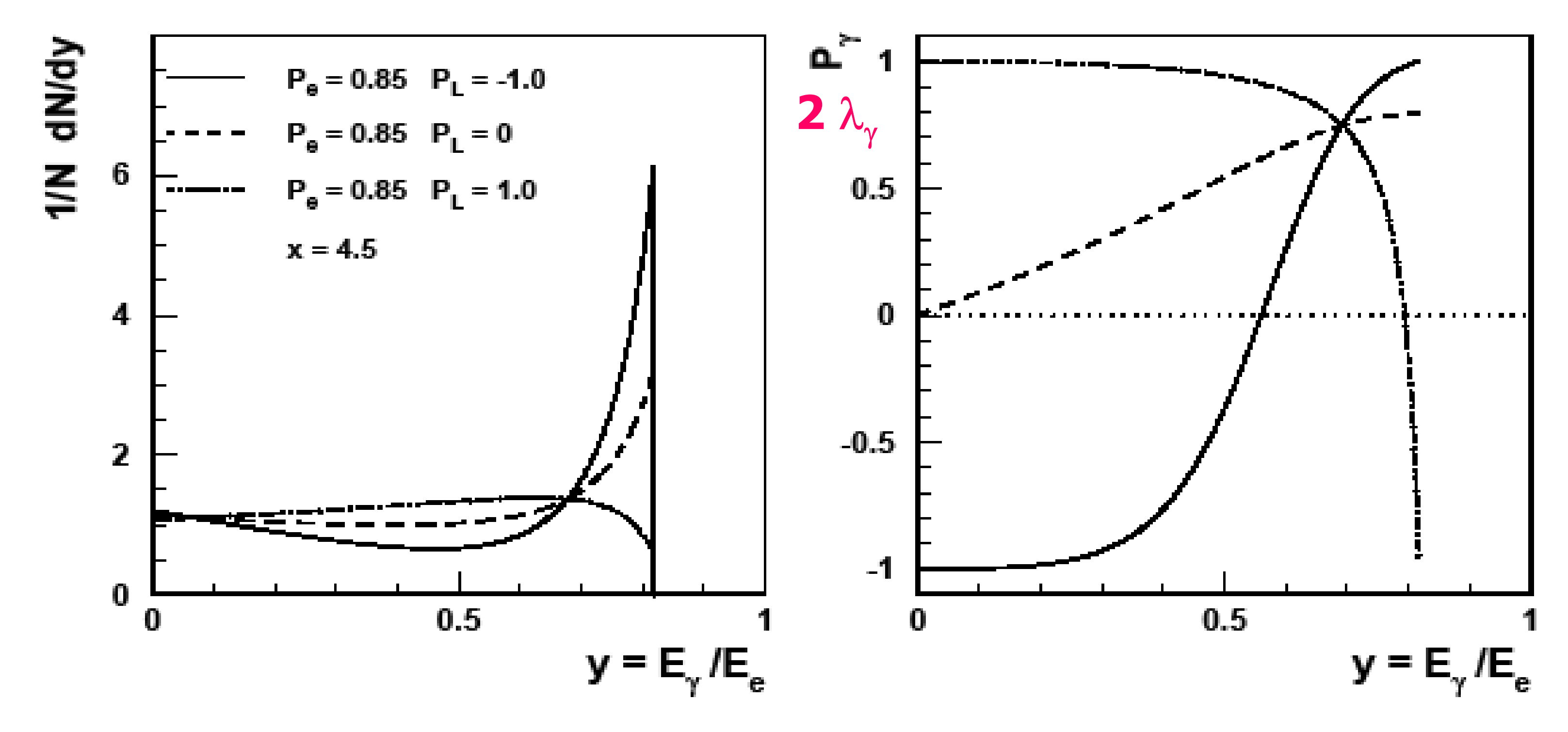
- For ILC with energy 500-1000 GeV:
- Characteristic energy $E_{\gamma\gamma}$ up to 0.8 E_ee (0.9 for $e\gamma$)
- Luminosity 0.2 L_ee

  Annual luminosity 100 fb_1 (30 fb-1 in the peak)
- Mean energy spread in a peak: ($E^2_{\gamma\gamma}$-0.07
- Mean helicity at the peak: 0.9-0.95

- Important parameter x: $\omega_{max} = \frac{x}{x+1} E_0, E_0$ energy of e

x=4.5 to avoid pair production

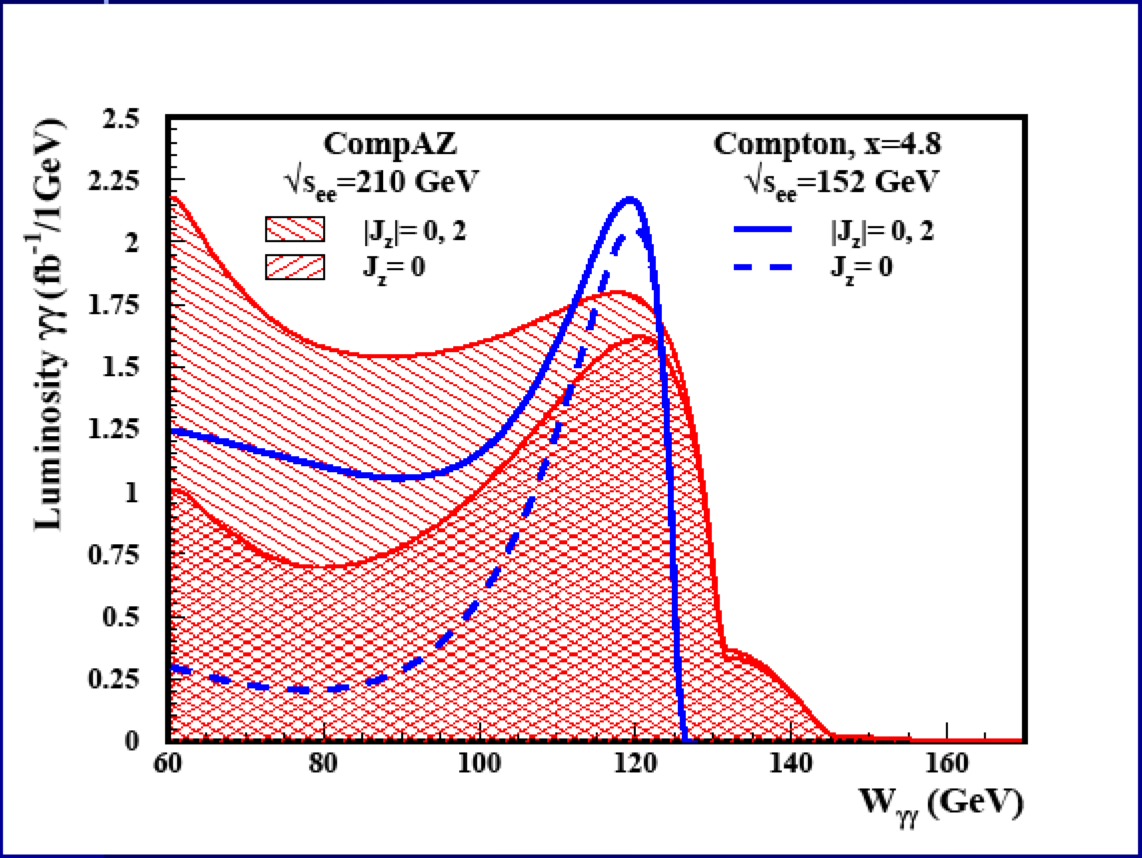
Spectra – dependence on polarization of e P_e and laser P_L



Ideal spectrum = the lowest order QED

Non-linear QED processes -> realistic spectrum for a single photon beam and for a $\gamma\gamma$ or e γ system

Realistic γ γ spectra -

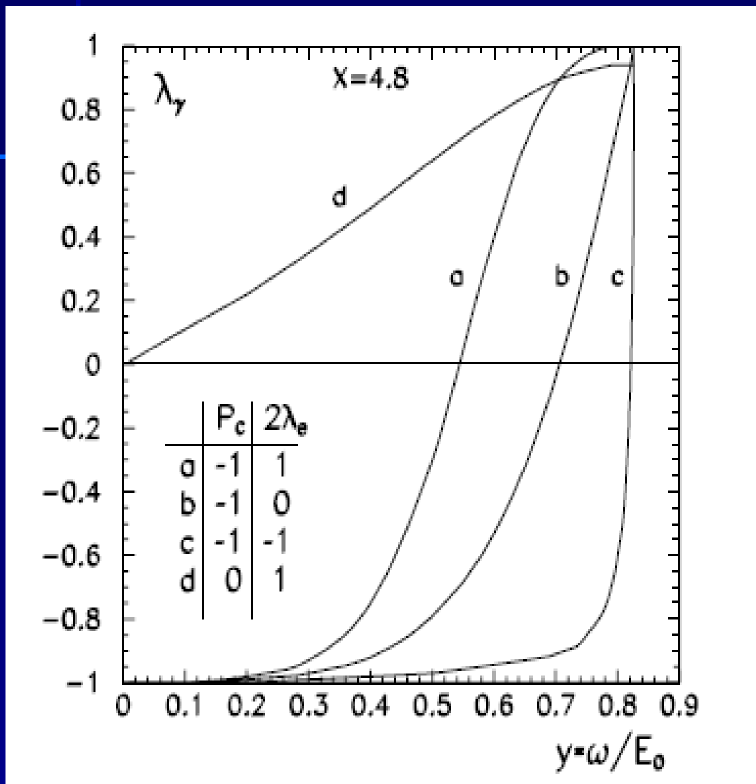


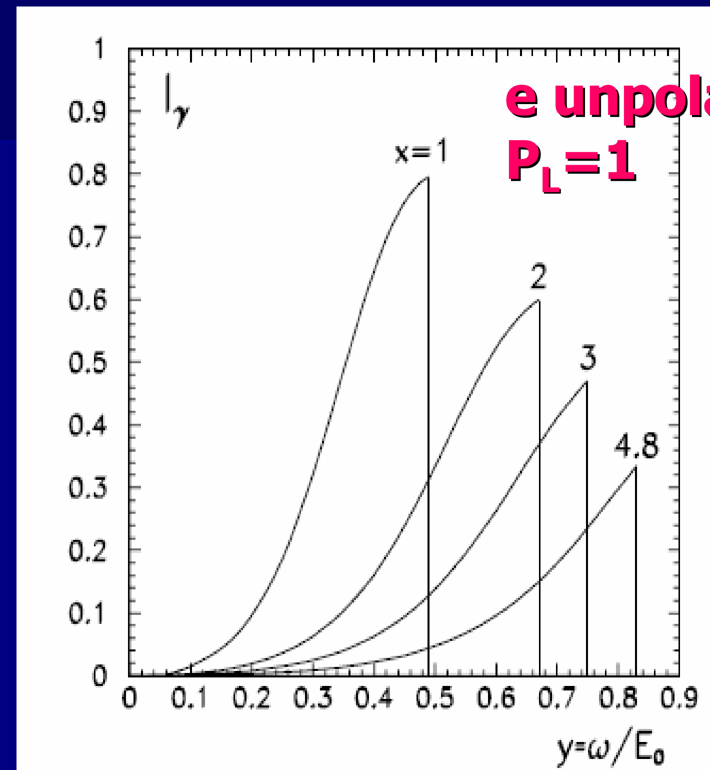
For J_z = 0, 2

Here peak for M=120 GeV

CompAZ parametrizaton (A.F.Żarnecki)

Circular and linear photon polarization at PLC





e unpolarized, $P_L=1$

Higgs production

$\sigma(\gamma\,\gamma \rightarrow h) \sim 1+\lambda_1\,\lambda_2$ $\quad J_z=0$

Main background

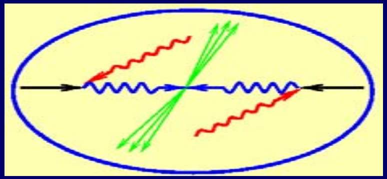
$\sigma(\gamma\,\gamma \rightarrow b\,b) \sim 1-\lambda_1\,\lambda_2$ $\quad J_z=2$

Higgs production

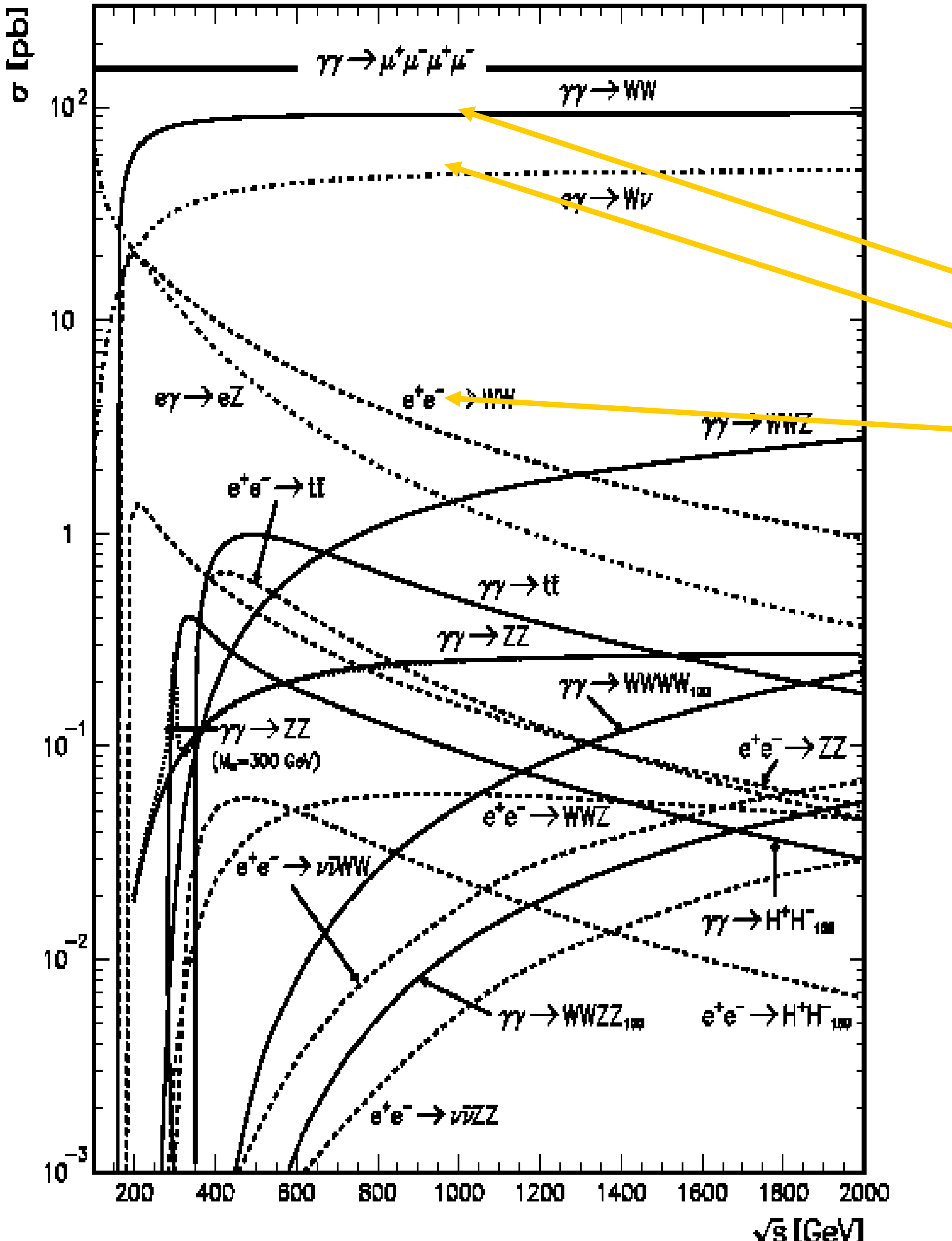
$\sigma(\gamma\,\gamma \rightarrow h) \sim 1 \pm l_1\,l_2$

CP even and CP odd

PLC: Photon Linear Collider
$\gamma\gamma$ and e γ



- Resonance production of C=+ states (eg. Higgs) Ginzburg et al
- Higher mass reach Spira, Zerwas
- Polarised beams – CP filter Gunion, Grzadkowski, Godbole, Zarnecki
- H $\gamma\gamma$ coupling – sensitive to charged particles in theory (nondecoupling) Ginzburg et al.., Gunion..
- Direct production of charged scalars, fermions and vectors – higher cross section Monig, Belanger
- Pair production of neutral particles (eg. light-on-light) via loops Jikia, Gounaris
- Study of hadronic interaction of the photon Godbole,Pancheri; MK Brodsky, deRoeck,Zerwa



WW or W ν

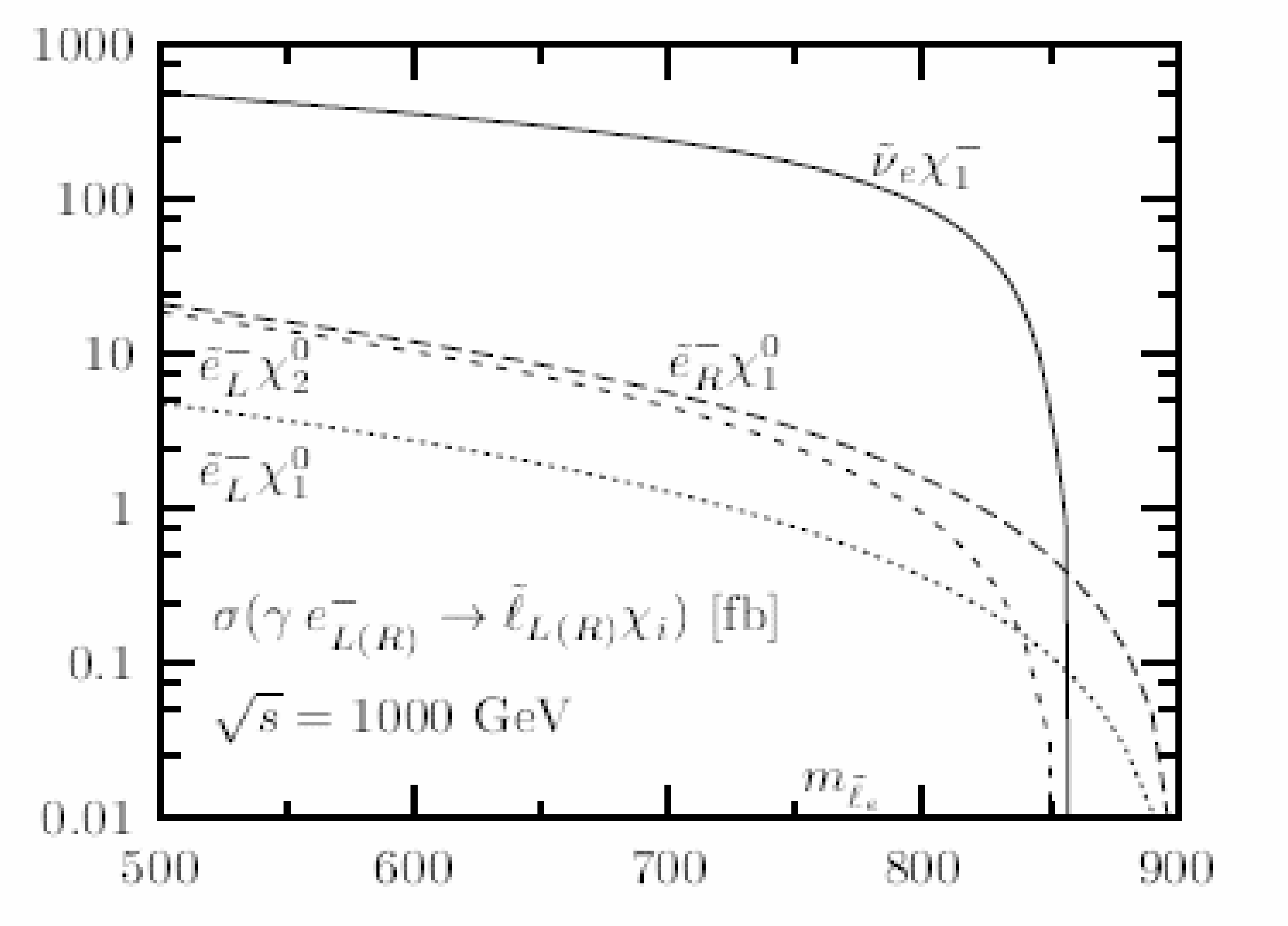
e γ

γ γ

e+e-

Belanger et al

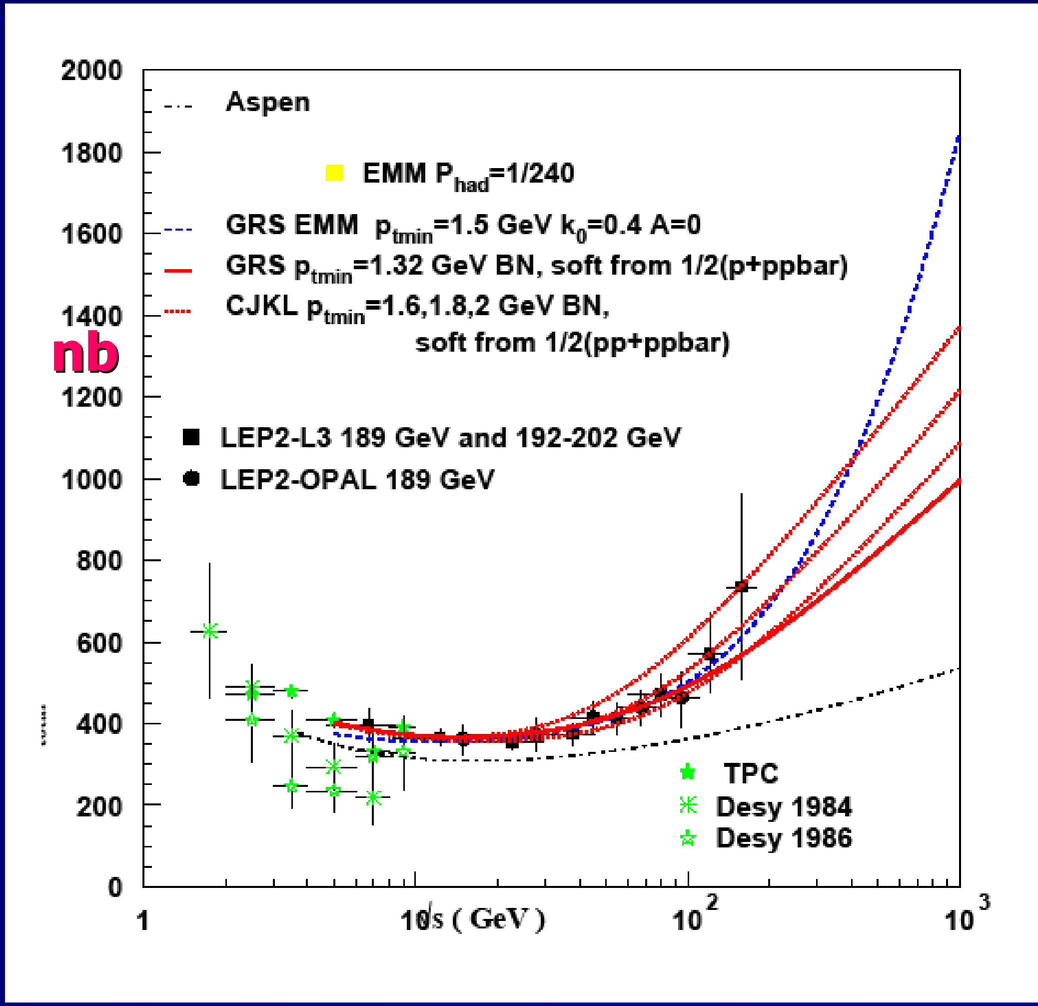
SUSY particle production
- in e γ higher mass reach



Hadronic cross section

Godbole,Pancheri,deRoeck

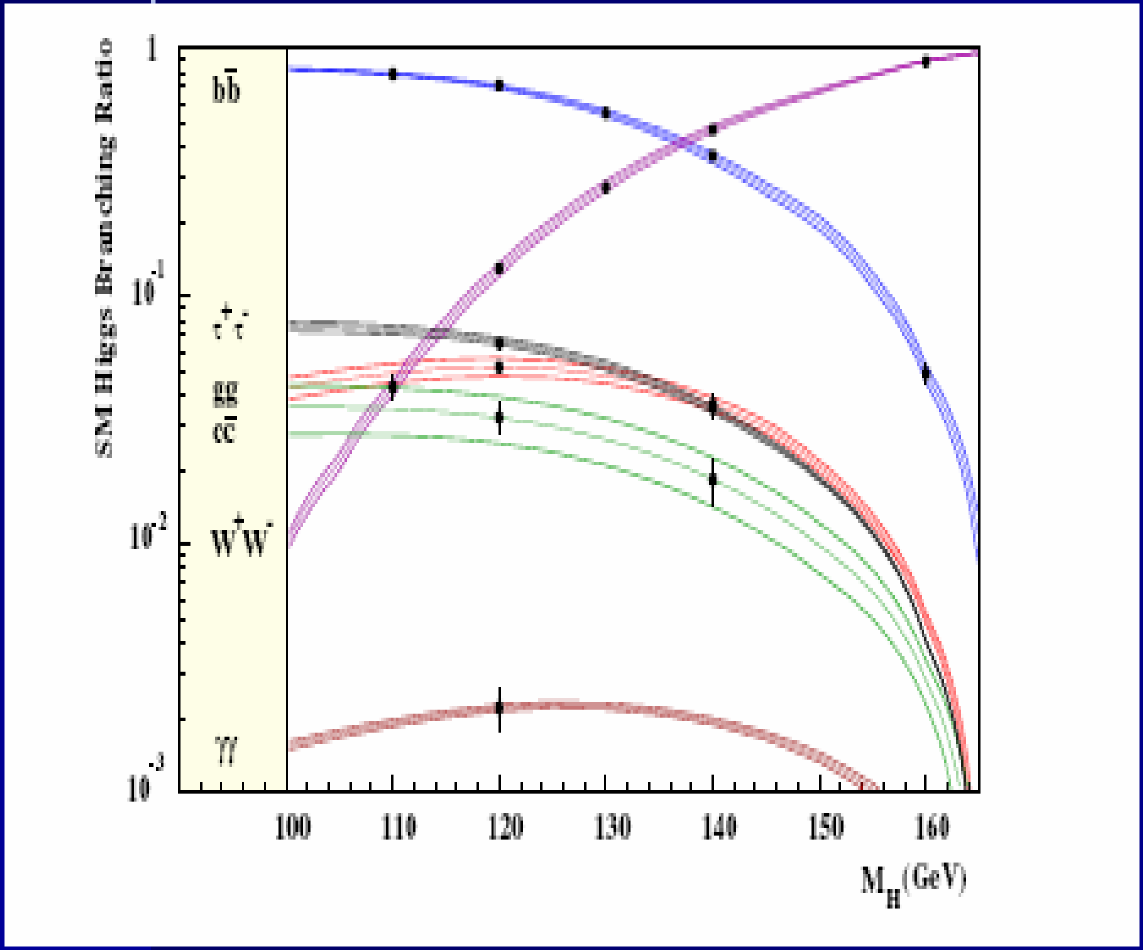
- Large $\gamma\,\gamma \rightarrow$ hadrons cross section
- Various study of QCD possible
- Measurements of the hadronic (partonic) structure of the photon
- In e γ option DIS on a <u>real</u> photon for the first time possible
- The structure of polarized photon



Precise Higgs Physics at ILC/PLC

- Precise measurements of Higgs production cross section and branching fractions.
- Higgs self coupling measurements
- Heavy Higgs searches in MSSM.
- CP of the Higgs boson.

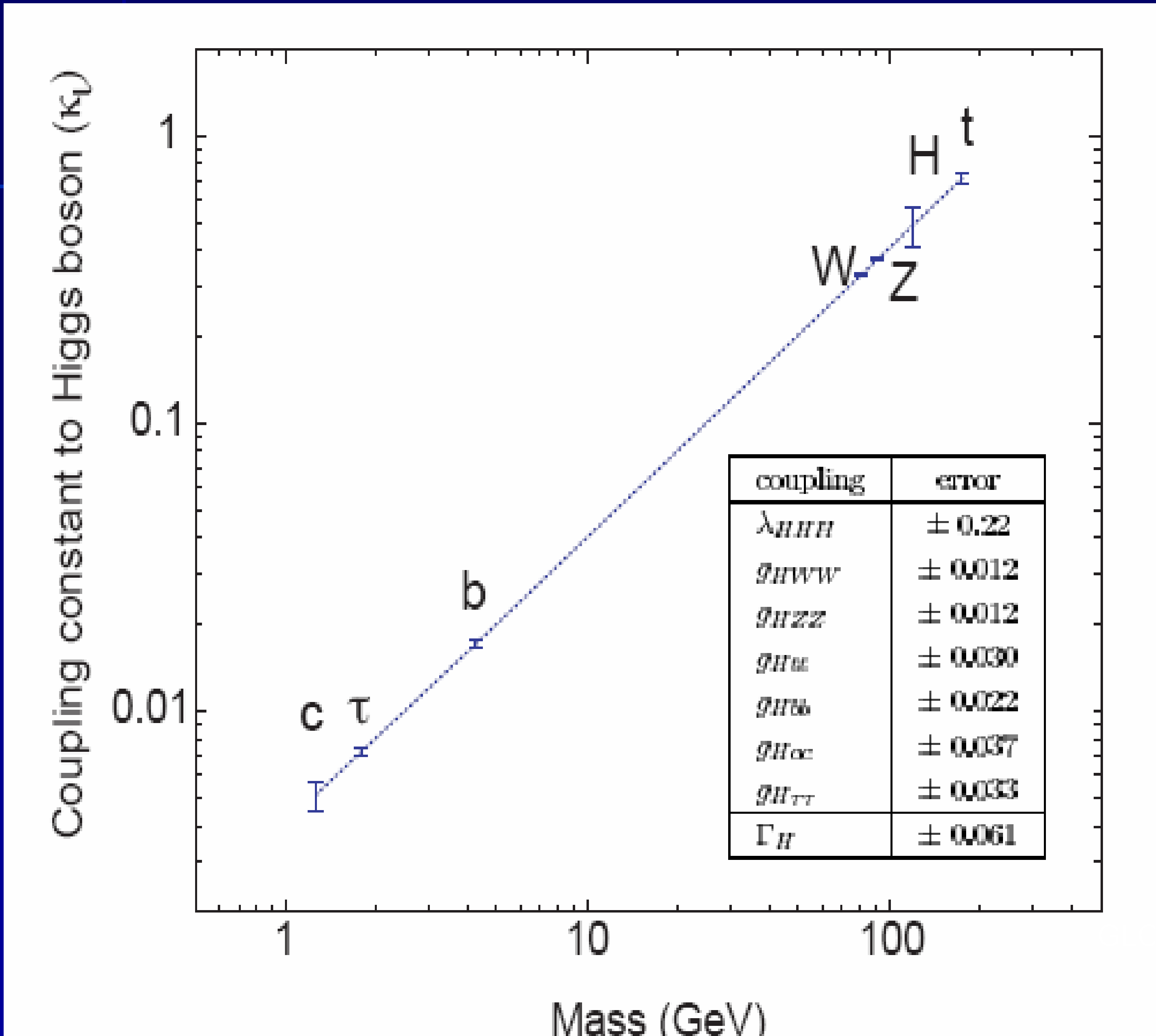
Br and relative precision at ILC e^+e^-



Decay mode	Relative precision (%)
$b\bar{b}$	1.0–2.4
$c\bar{c}$	8.1–12.3
$\tau^+\tau^-$	4.6–7.1
gg	4.8–10
WW	3.6–5.3
$\gamma\gamma$	23–35

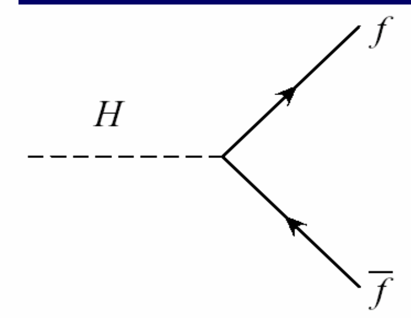
Br for 120 GeV, 500 fb-1

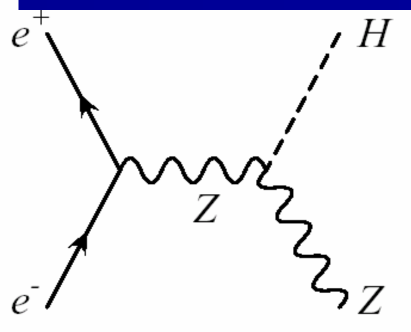
Proof of the mass generation mechanism of elementary particles

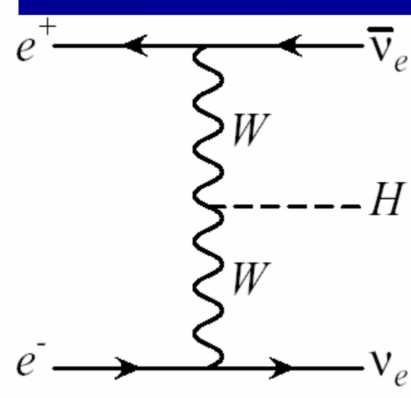


coupling	error
λ_{HHH}	± 0.22
g_{HWW}	± 0.012
g_{HZZ}	± 0.012
g_{Htt}	± 0.030
g_{Hbb}	± 0.022
g_{Hcc}	± 0.037
$g_{H\tau\tau}$	± 0.033
Γ_H	± 0.061

e^+e^-



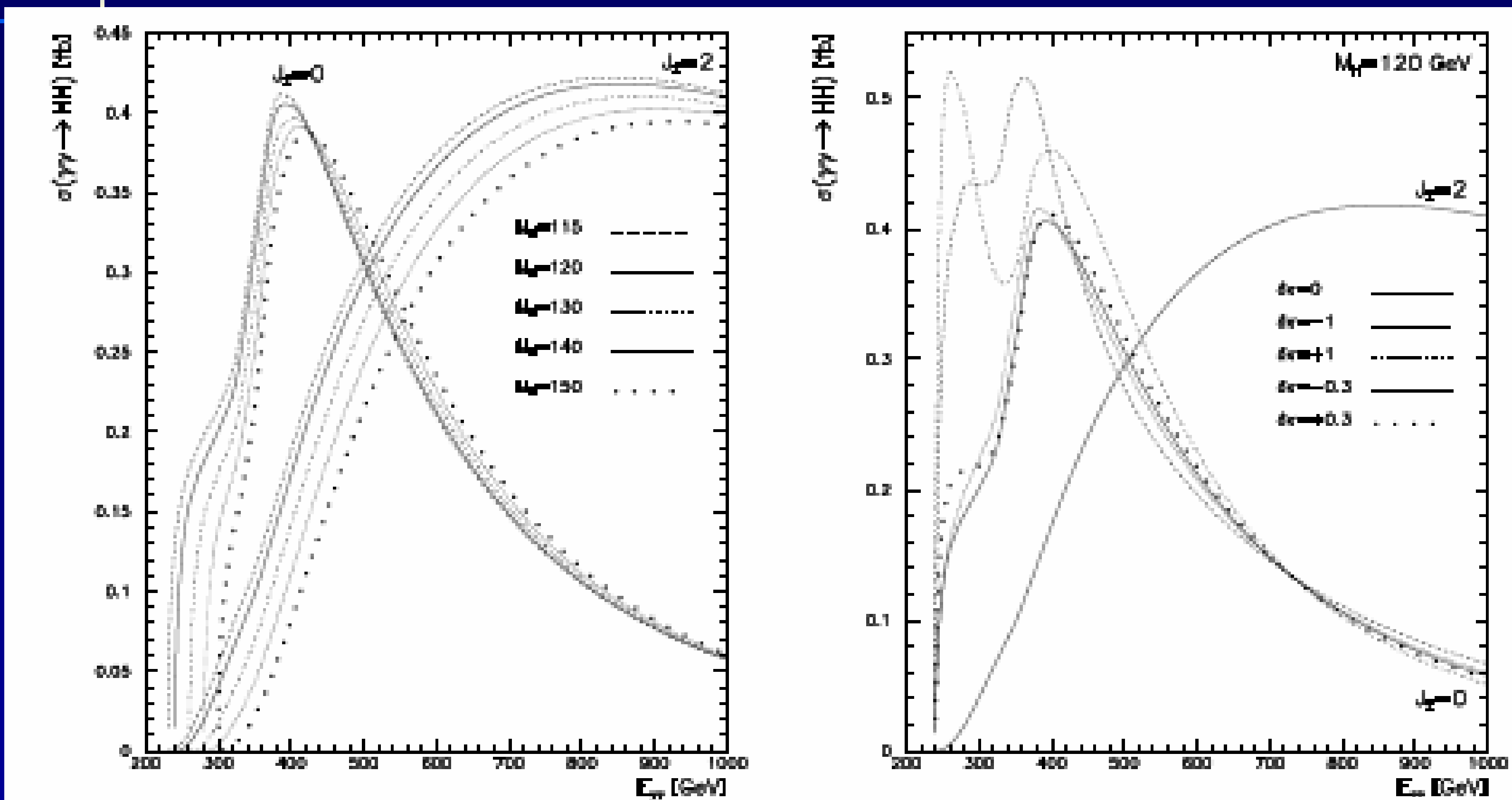




Self couplings in $\gamma\gamma \to hh$

Belusevic, Jikia '2004

box, triangle with W,top and h*->hh



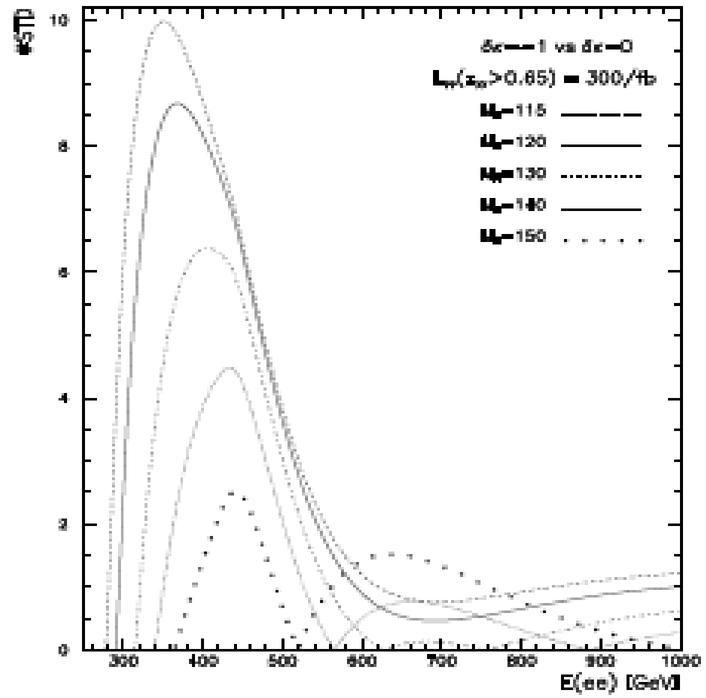
$$\bar{\lambda}_{HHH} = (1 + \delta\kappa)\lambda_{HHH}$$

Cross section for mass 115-150 GeV for J_z=0, 2

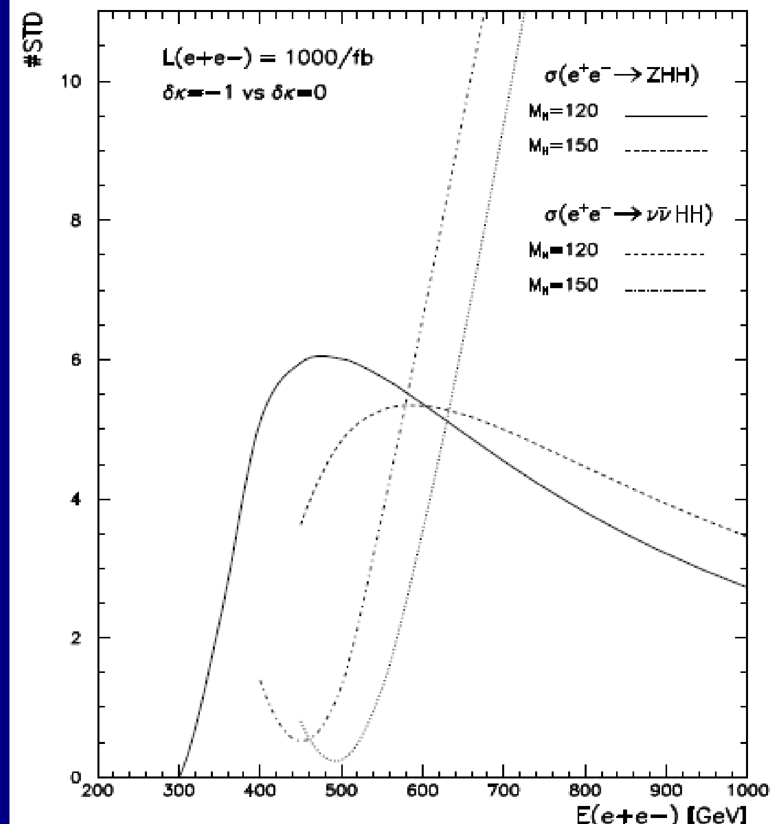
For mass = 120 GeV, anomalous contr. $|\delta|$=0,1,0.3

σ for hhh coupling vs SM

γ γ



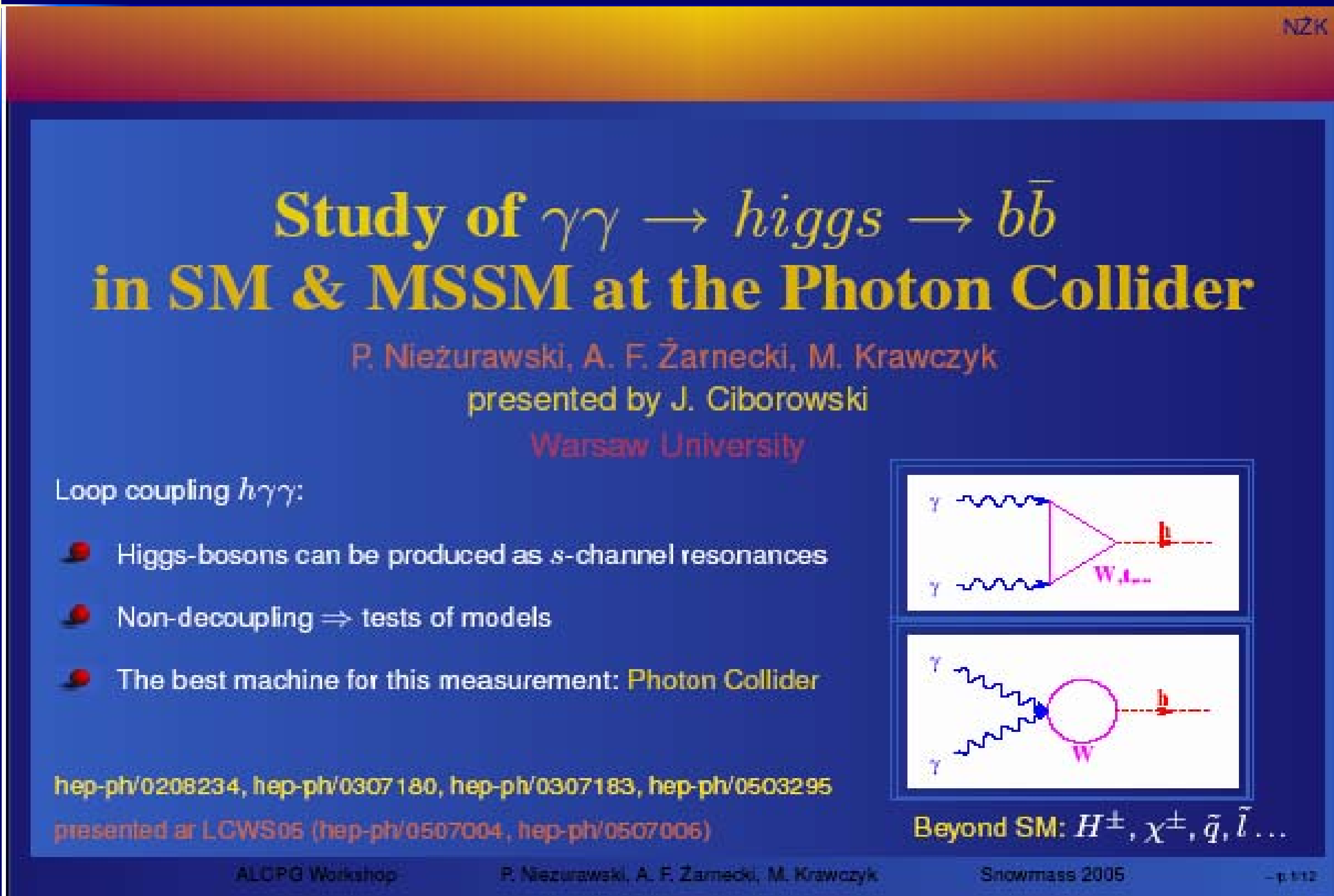
e^+e^-



$$\#STD = \frac{|\sigma(\delta\kappa = 0) - \sigma(\delta\kappa = -1)|}{\sqrt{\sigma(\delta\kappa = 0)}}\sqrt{L_{\gamma\gamma}}$$

δ=-1 cancels the SM hhh contr.

SM Higgs decaying in b $\bar{b}$



Higgs coupling to $\gamma\gamma$

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

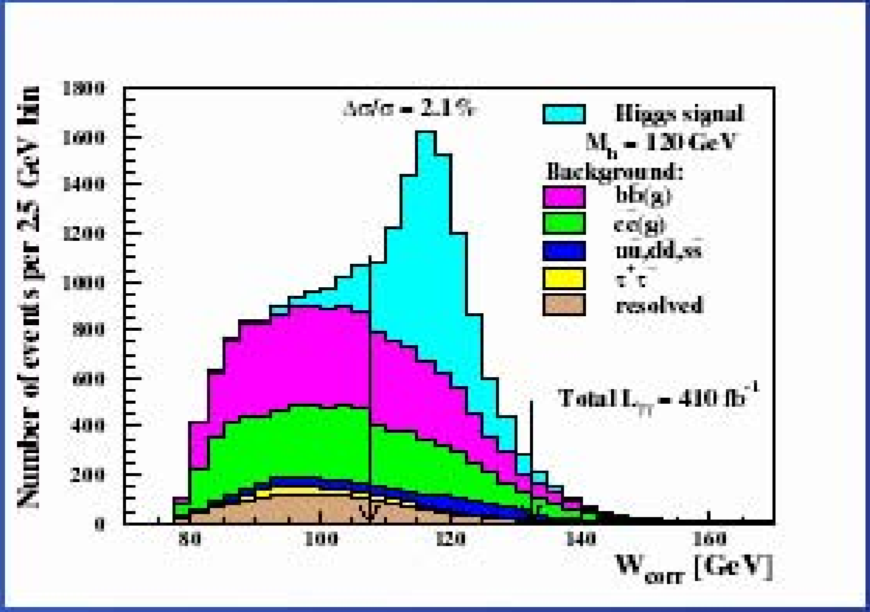
Niezurawski et al.,

Monig, Rosca

SM summary

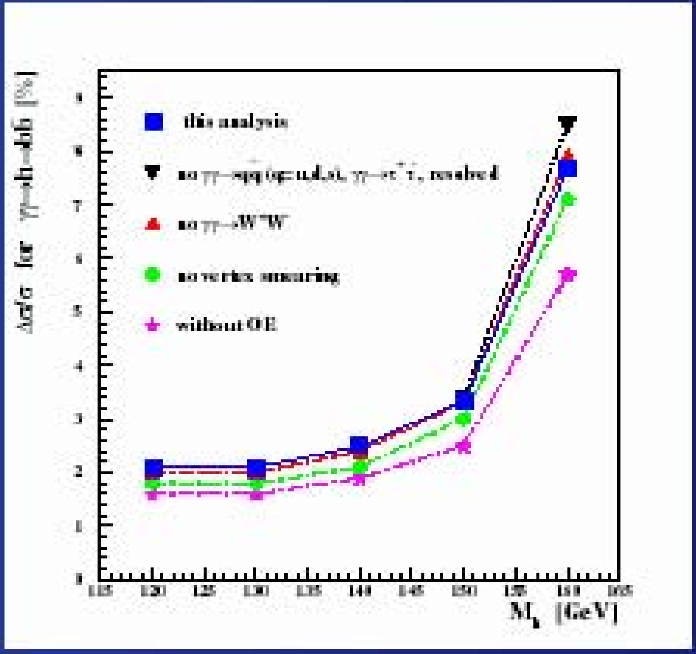
NZK

Results for $M_h = 120$ GeV



Corrected invariant mass distributions for signal and background events

Results for $M_h = 120$-160 GeV

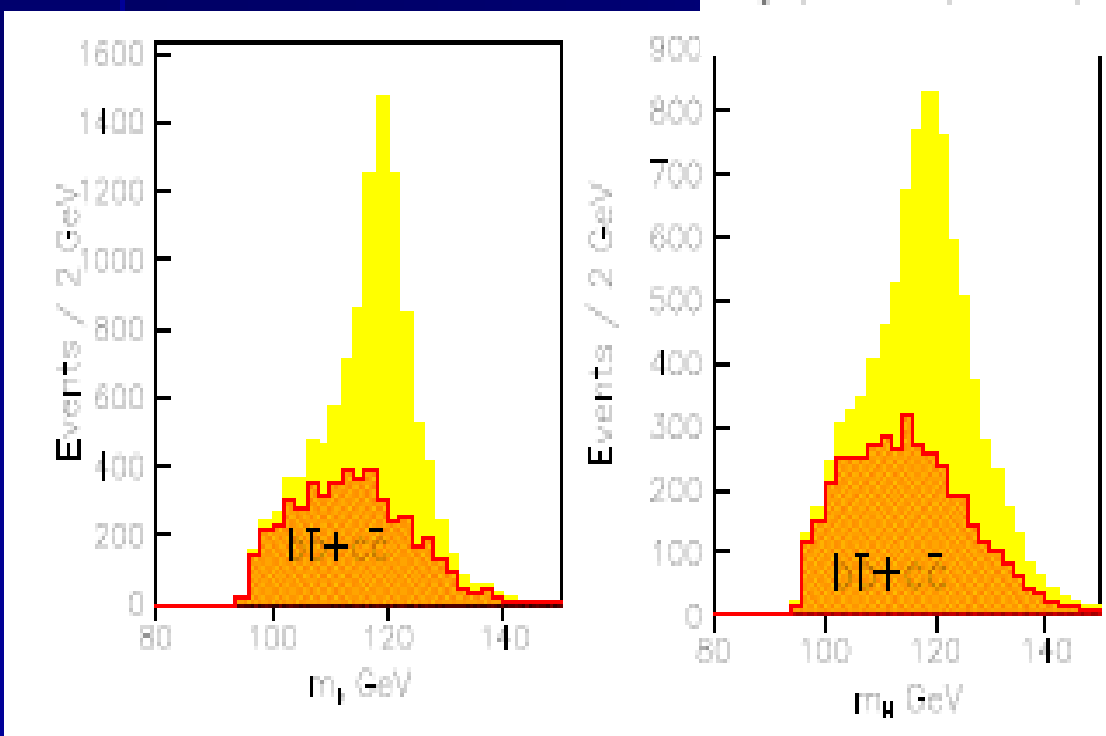


For $M_h = 150$, 160 GeV additional cuts to reduce $\gamma\gamma \to W^+W^-$

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

- Without and with overlying events

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



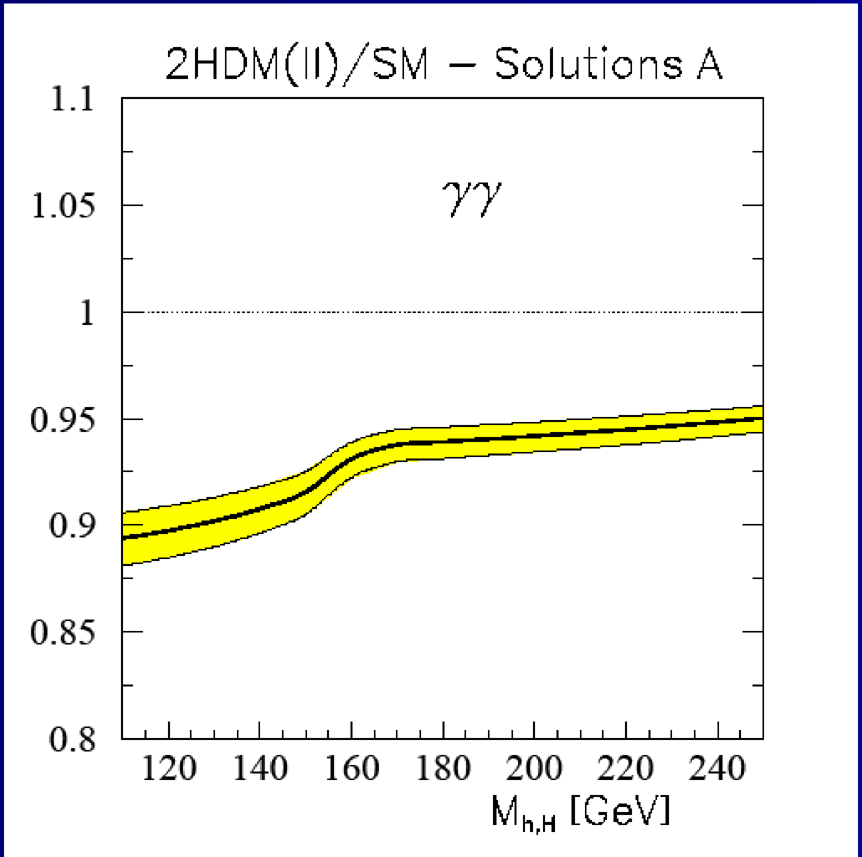
2.1 %

Knowing it and using Br from e^+e^-

->

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

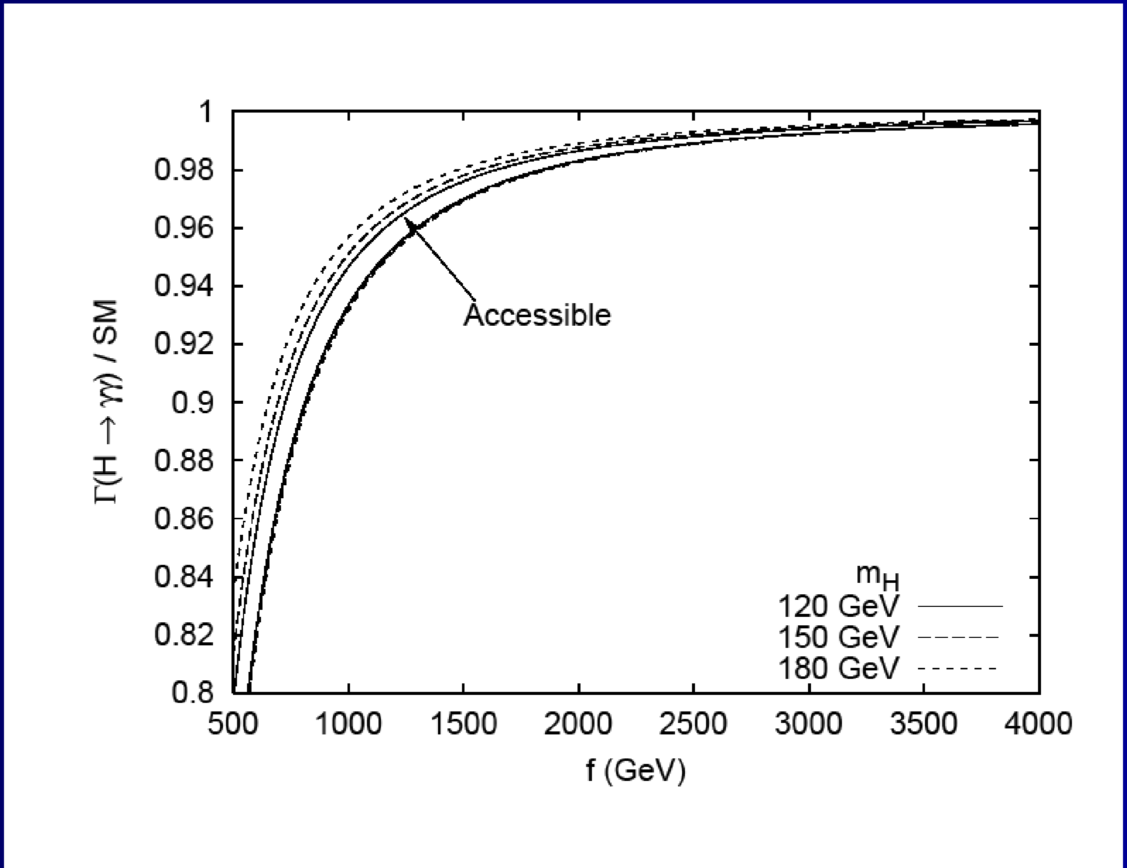
SM-like h (or H) in 2HDM all couplings to fermions and gauge bososns as in SM



Effect due to H^+ contributions (600-800 GeV)

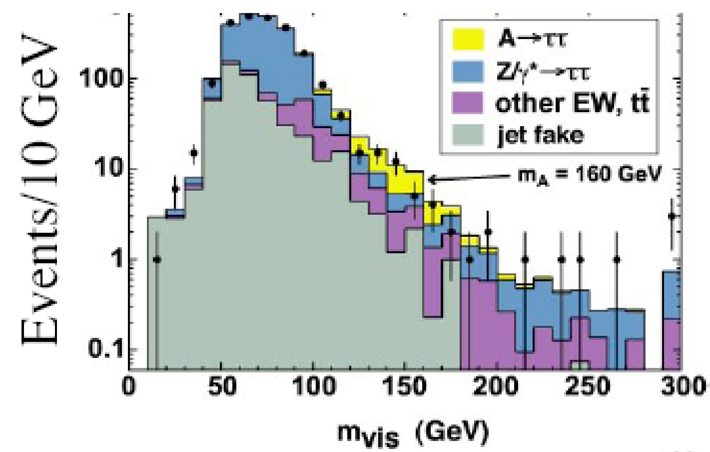
Ginzburg, Osland, MK - 2001

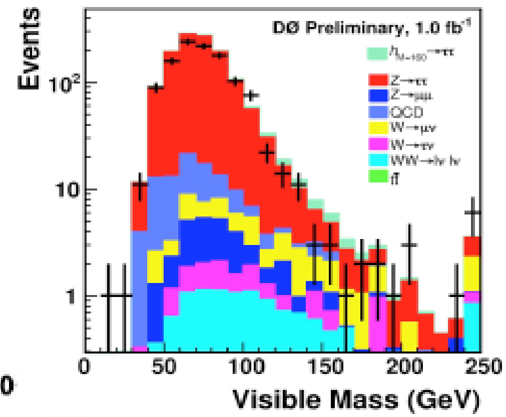
Littlest Higgs model

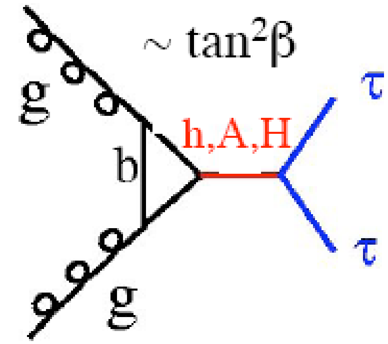


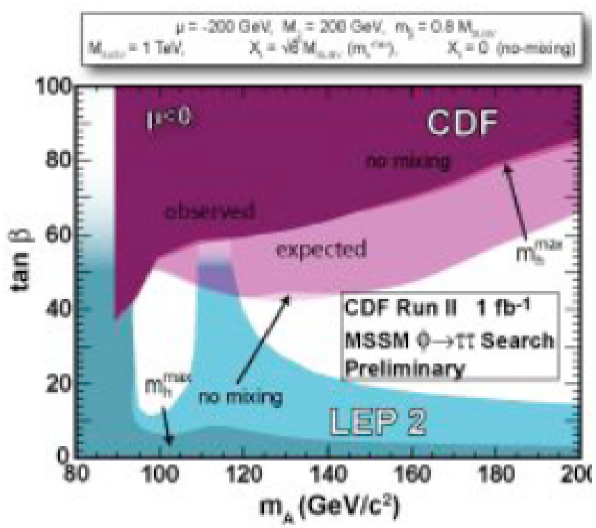
f – scale of new heavy particle;
Han,Logan,McElrath,Wang 2003

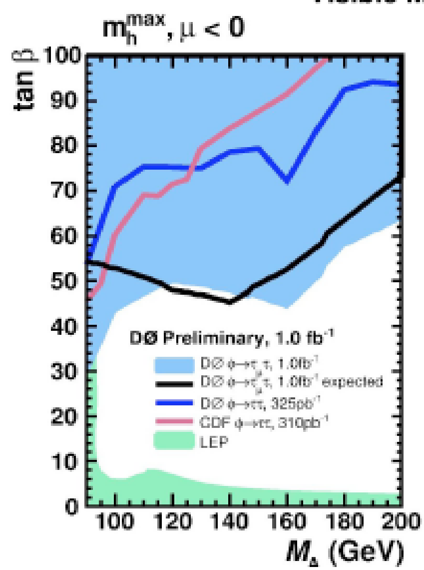
MSSM Higgs Boson Search





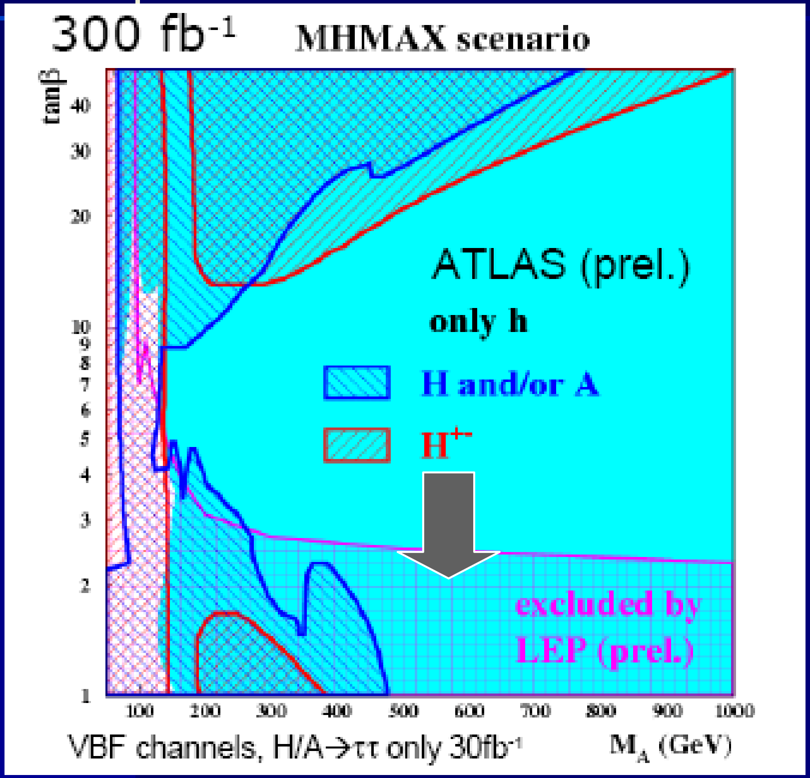






- Data mass distribution agrees with SM expectation mostly:
  - CDF: Slight excess has a significance of 2.1σ (cross section about 2 pb)
  - DØ: slight deficit in that region

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



at least 1 Higgs boson is observable

• in some parts >1 Higgs bosons observable in the whole parameter space

• but large area in which only one Higgs boson h (SM-like) observable

LHC wedge

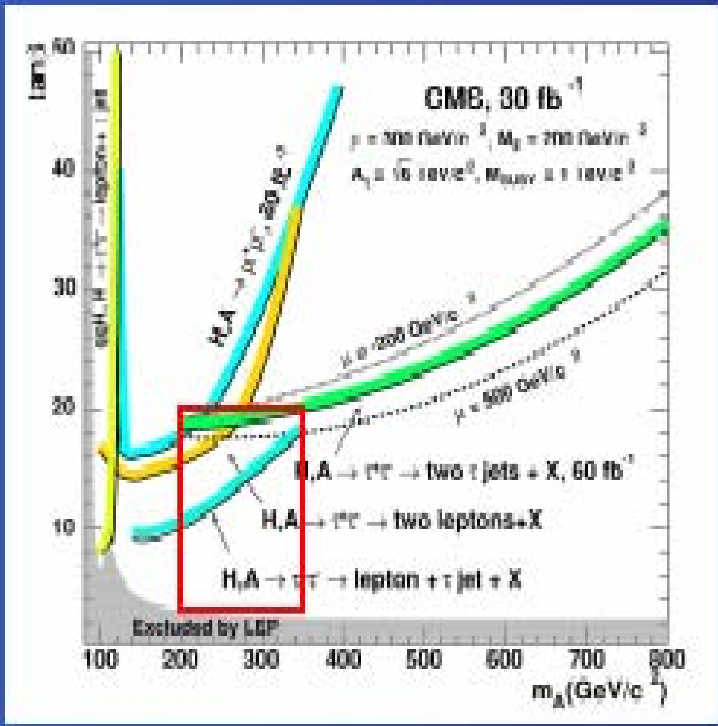
Result assuming no H→SUSY

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

NŻK

MSSM: LHC wedge at PLC

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]	$A_{\tilde{f}}$ [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 $A_{\tilde{f}}$ to have M_h above 114 GeV

II – an intermediate scenario

IV – as in CMS NOTE 2003/033

MSSM: Precision at PLC

Spira et al

Niezurawski et al.,- simulation

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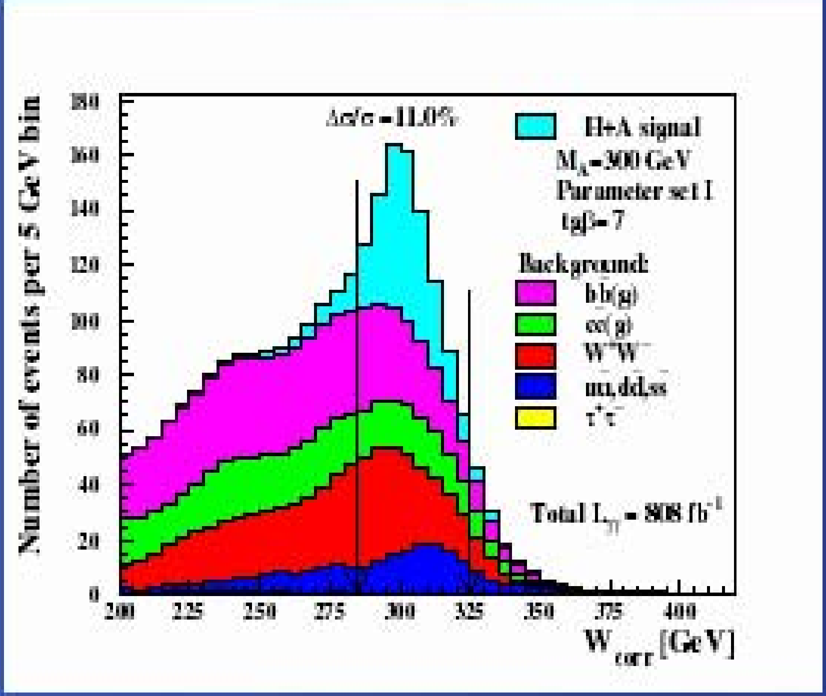
Covering the LHC wedge

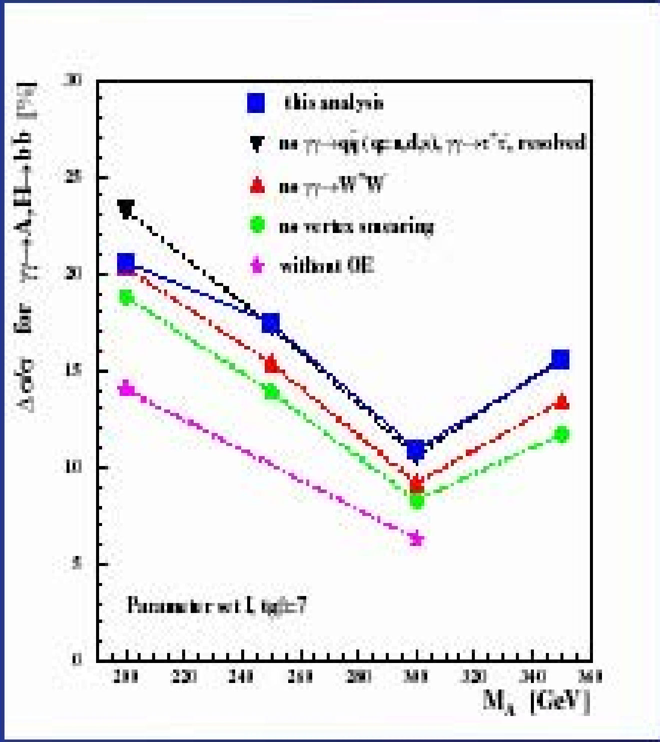
Precision of $\sigma(\gamma\gamma \rightarrow A, H \rightarrow b\bar{b})$ mesurement

Results for M_A = 300 GeV



Corrected invariant mass distributions

Results for M_A = 200-350 GeV



our previous results compared

Precision & Significance

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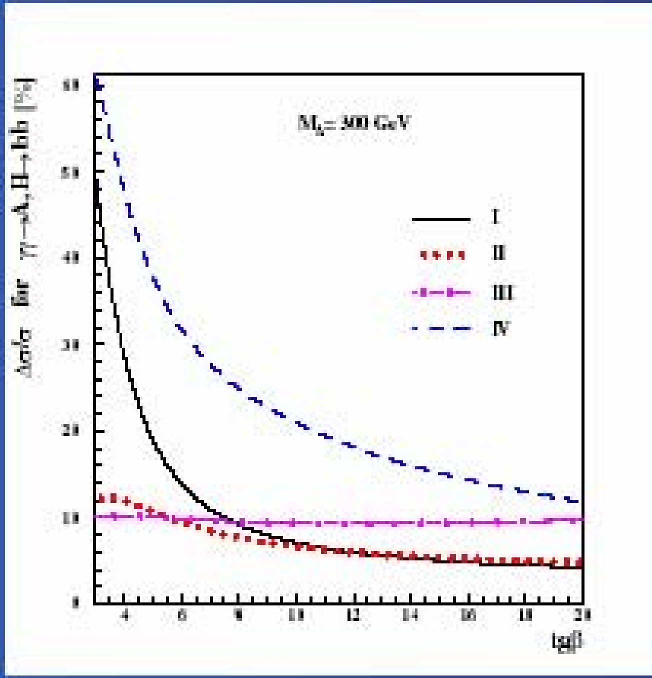
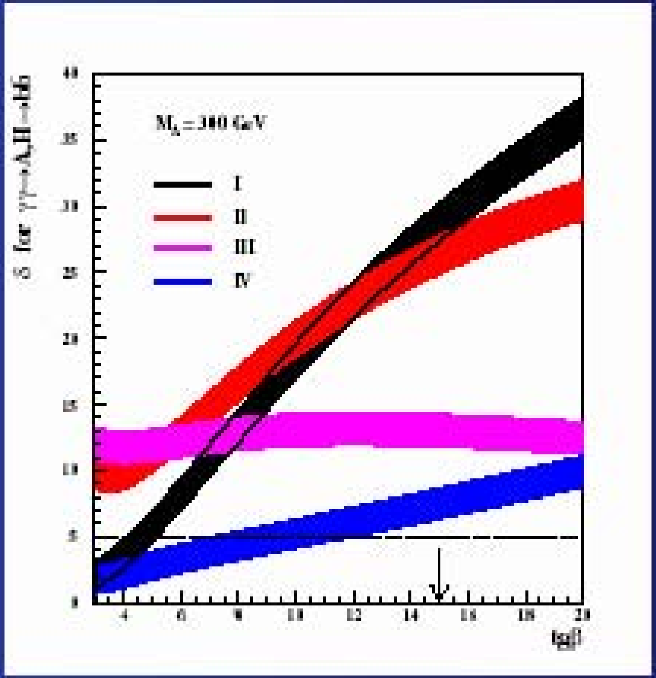
$\Delta\sigma(\gamma\gamma \to A, H \to b\bar{b})/\sigma(\gamma\gamma \to A, H \to b\bar{b})$



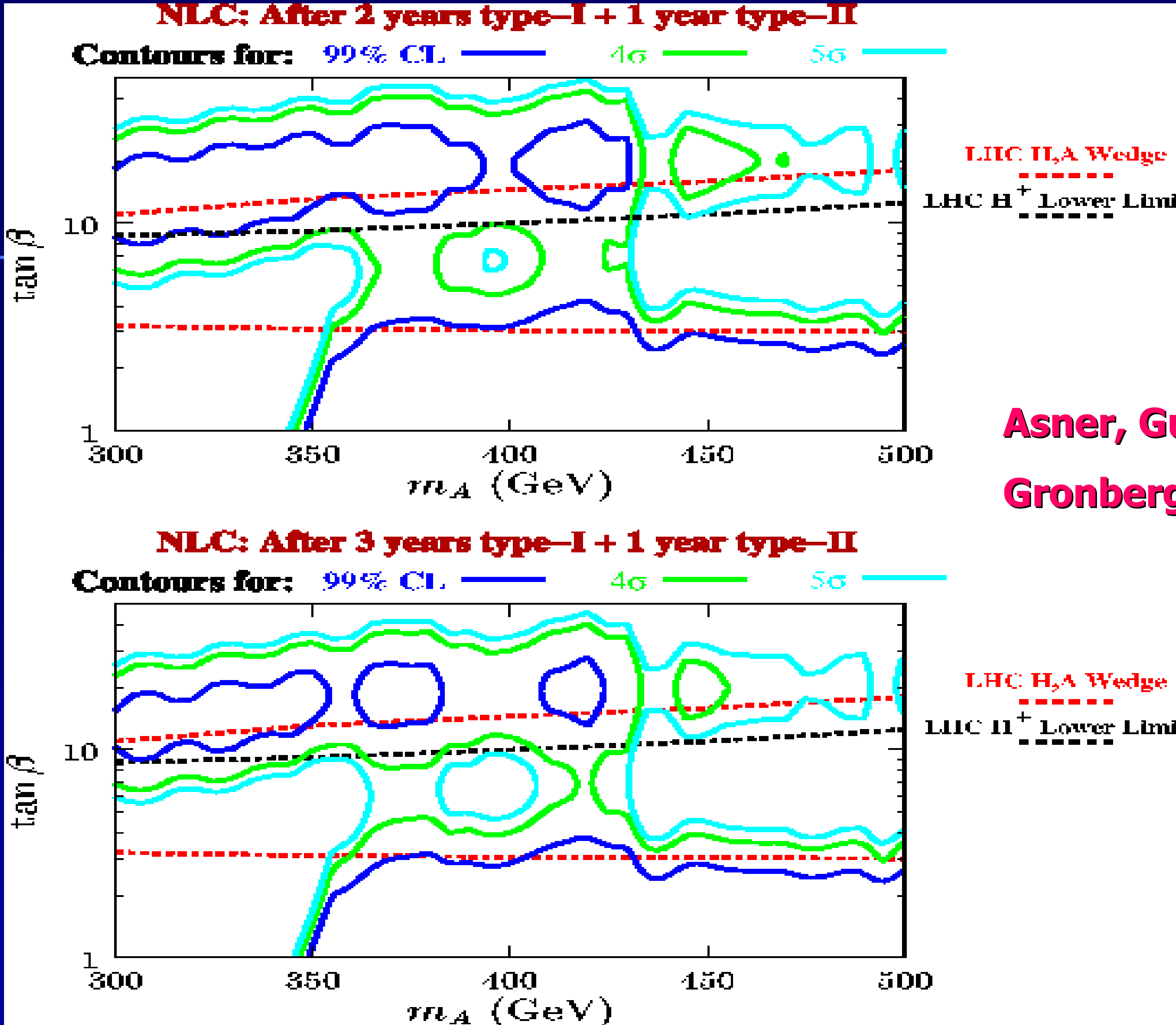
Significance for $\gamma\gamma \to A, H \to b\bar{b}$



$$\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{\mu_S + \mu_B}}{\mu_S}$$

$$\delta = \frac{\mu_S}{\sqrt{\mu_B}} \pm \sqrt{1 + \frac{\mu_S}{\mu_B}}$$

Arrow – lower limit at LHC



Asner, Gunion, Gronberg

S.Y.Choi,J.Kalinowski,J.S.Lee, M.M. Muhlleitner, M.Spira,P.M.Zerwas-0404119

Determining tan β in τ-τ fusion to Susy Higgs Bosons at the PLC

Zerwas et al

Methods to determine $\tan\beta$ for large values beyond $\tan\beta = 10$

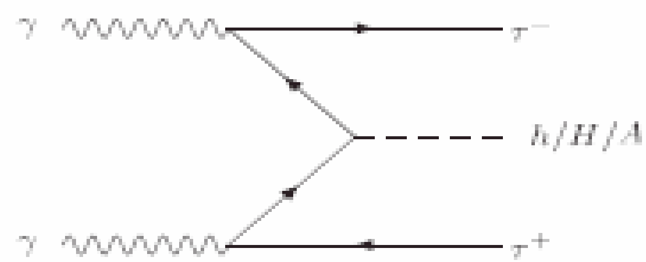
(a) charginos / neutralinos	$\Rightarrow$	$\cos 2\beta$ slope $\sim 1/\tan^3\beta$ insensitive	Choi et al
(b) τ polarization etc	$\Rightarrow$	$\sim 10\%$	Boos et al
(c) bbH/A, H/A widths etc	$\Rightarrow$	LHC$/300 fb^{-1}$: 12 to 4%	Gunion et al
	$\Rightarrow$	LC$/2,000 fb^{-1}$: 5 to 3% at $M_A = 200$GeV	
(d) LHC sim $H/A \to \tau\tau$	$\Rightarrow$	$30 fb^{-1}$ $\sim 20\%$	Kinnunen et al
(e) $\gamma\gamma \to H/A \to b\bar{b}$	$\Rightarrow$	~ 4 to 10% [estimate]	see: Niezurawski et al and Velasco et al

Additional methods strongly required for precision analysis of $\tan\beta$ 2

Tau fusion -> tan beta

New method: Tauon fusion of Higgs $h/H/A/$ at $\gamma\gamma$ collider:

$$\gamma\gamma \to (\tau^+\tau^-)(\tau^+\tau^-) \to \tau^+\tau^- + h/H/A$$



couplings: for large $\tan\beta$

$$A\tau\tau = \tan\beta,\ H\tau\tau \simeq \tan\beta \quad \text{for } A, H \text{ heavy}$$
$$h\tau\tau \simeq \tan\beta \quad\quad A \text{ light}$$

Higgs decays: $h/H/A \to bb$ at 90% level $\Rightarrow$ SPS1b

- Background included

Accuracy ...

RESULTS: $E_{e^-e^-} = 800/500$ GeV $\Rightarrow$ $E_{\gamma\gamma} = 600/400$ GeV

$\mathcal{L} = 200/100\ \text{fb}^{-1}$

(a) Cross sections $h/H/A$: for $\tan\beta = 10$ to 50

$\sigma(H/A) = 3$ to 1 fb for $M_{A/H} = 100$ to 500 GeV at $\tan\beta = 30$

$\sigma(h) = 5$ fb for $M_h = 110$ GeV at $\tan\beta = 30$

(b) Errors $\Leftarrow$ matching and improving on alternative methods:

	$E_{\gamma\gamma} = 400$ GeV, $\mathcal{L} = 100\ \text{fb}^{-1}$			$E_{\gamma\gamma} = 600$ GeV, $\mathcal{L} = 200\ \text{fb}^{-1}$				
M_{Higgs}	$A \oplus h$	$A \oplus H$		$A \oplus h$	$A \oplus H$			
[GeV]	100	200	300	100	200	300	400	500
$\tan\beta$	I	II	III	IV	V	VI	VII	VIII
10	8.4%	10.7%	13.9%	8.0%	9.0%	11.2%	13.2%	16.5%
30	2.6%	3.5%	4.6%	2.4%	3.0%	3.7%	4.4%	5.3%
50	1.5%	2.1%	2.7%	1.5%	1.8%	2.2%	2.6%	3.2%

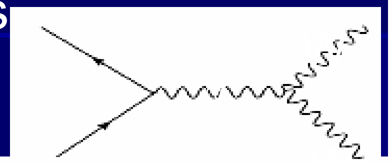
$\Delta\tan\beta \simeq 0.9$ to 1.3 uniform in $\tan\beta$

for all M_A up to kin. limit

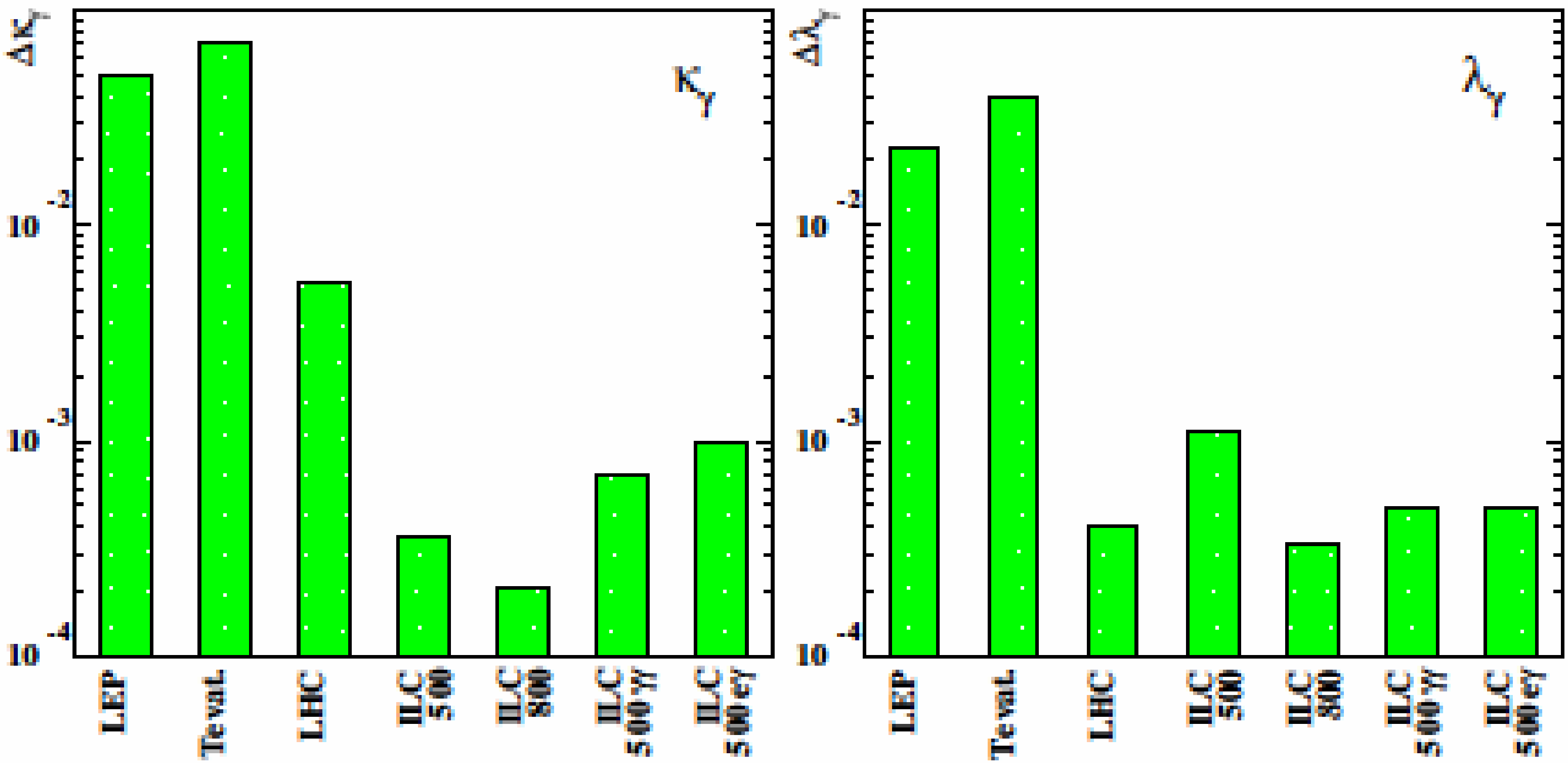
Coupling of Gauge Bosons

- Fermion pair production at 500 GeV and the Z pole (GigaZ)
- Coupling among gauge bosons

anomalous couplings
(V_mu nu and dual)



$$+\,\mathrm{i}\tilde{\kappa}_V W^-_\mu W^+_\nu \tilde{V}_{\mu\nu} + \mathrm{i}\frac{\tilde{\lambda}_V}{m_W^2} W^-_{\lambda\mu} W^+_{\mu\nu} \tilde{V}_{\nu\lambda}]$$



A. Manteuffel

Anomalous Couplings in γγ→WW

Gauge and gauge-Higgs anomalous couplings

$$\mathscr{L}_2 = \frac{1}{v^2}\left(h_W O_W + h_{\tilde W} O_{\tilde W} + h_{\varphi W} O_{\varphi W} + h_{\varphi \tilde W} O_{\varphi \tilde W} + h_{\varphi B} O_{\varphi B} + h_{\varphi \tilde B} O_{\varphi \tilde B} + h_{WB} O_{WB} + h_{\tilde W B} O_{\tilde W B} + h_\varphi^{(1)} O_\varphi^{(1)} + h_\varphi^{(3)} O_\varphi^{(3)}\right),$$

$$O_W = \epsilon_{ijk}\, W_\mu^{i\,\nu} W_\nu^{j\,\lambda} W_\lambda^{k\,\mu}, \qquad O_{\tilde W} = \epsilon_{ijk}\, \tilde W_\mu^{i\,\nu} W_\nu^{j\,\lambda} W_\lambda^{k\,\mu},$$

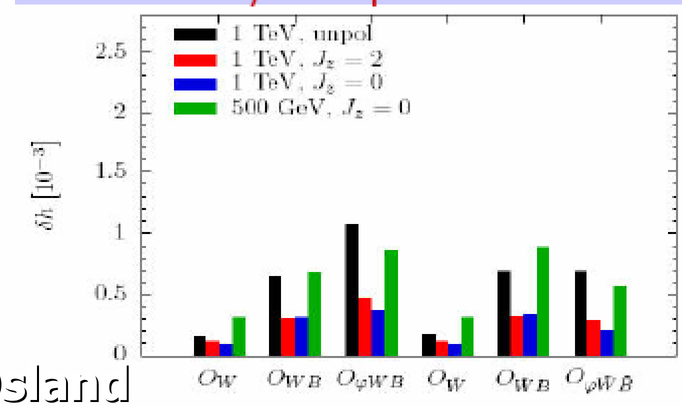
$$O_{\varphi W} = \frac{1}{2}\left(\varphi^\dagger \varphi\right) W^i_{\mu\nu} W^{i\,\mu\nu}, \qquad O_{\varphi \tilde W} = \left(\varphi^\dagger \varphi\right) \tilde W^i_{\mu\nu} W^{i\,\mu\nu},$$

$$O_{\varphi B} = \frac{1}{2}\left(\varphi^\dagger \varphi\right) B_{\mu\nu} B^{\mu\nu}, \qquad O_{\varphi \tilde B} = \left(\varphi^\dagger \varphi\right) \tilde B_{\mu\nu} B^{\mu\nu},$$

$$O_{WB} = \left(\varphi^\dagger \tau^i \varphi\right) W^i_{\mu\nu} B^{\mu\nu}, \qquad O_{\tilde W B} = \left(\varphi^\dagger \tau^i \varphi\right) \tilde W^i_{\mu\nu} B^{\mu\nu},$$

$$O_\varphi^{(1)} = \left(\varphi^\dagger \varphi\right) \left(\mathcal{D}_\mu \varphi\right)^\dagger \left(\mathcal{D}^\mu \varphi\right), \qquad O_\varphi^{(3)} = \left(\varphi^\dagger \mathcal{D}_\mu \varphi\right)^\dagger \left(\varphi^\dagger \mathcal{D}^\mu \varphi\right)$$

Sensitivity with polarized beams



Comparison of Sensitivities

	LEP & SLD (*)	$ee \to WW$ (*)	$\gamma\gamma \to WW$ unpolarised	$\gamma\gamma \to WW$ $J_z = 0$
	$h_i\ [10^{-3}]$	$\delta h_i\ [10^{-3}]$	$\delta h_i\ [10^{-3}]$	$\delta h_i\ [10^{-3}]$
h_W	-69 ± 39	0.3	0.6	0.3
h_{WB}	-0.06 ± 0.79	0.3	1.6	0.7
$h_{\varphi WB}$	×	×	2.2	0.9
$h_\varphi^{(3)}$	-1.15 ± 2.39	36.4	×	×
$h_{\tilde W}$	68 ± 81	0.3	0.7	0.3
$h_{\tilde W B}$	33 ± 84	2.2	2.0	0.9
$h_{\varphi \tilde W B}$	×	×	2.0	0.6

From P. Osland

Neutral Higgs bosons decaying into WW/ZZ pairs with mass above 200 GeV

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

A.F. Żarnecki, Warsaw University
with P. Nieżurawski and M. Krawczyk
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

LHC

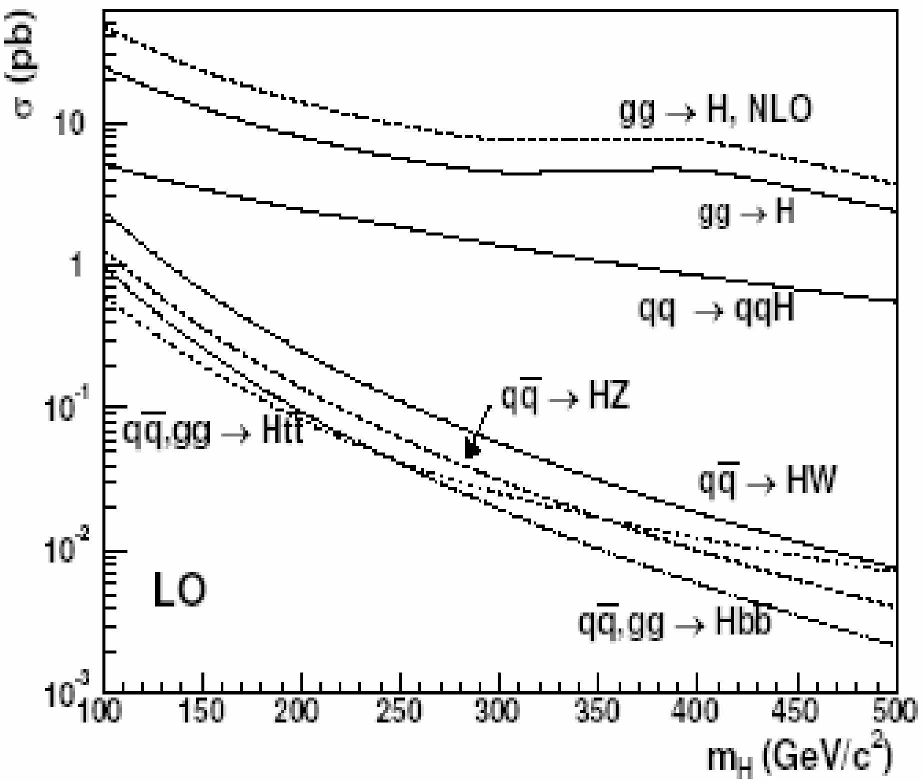
In the considered mass range Higgs boson production at LHC is dominated by the gluon fusion process.

Γ_{hgg} is dominated by the top loop contribution ⇒

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

WW fusion process contributes to about 15% of cross section

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



SM Higgs boson production at LHC

LHC

Measurement of the production cross section times branching ratio

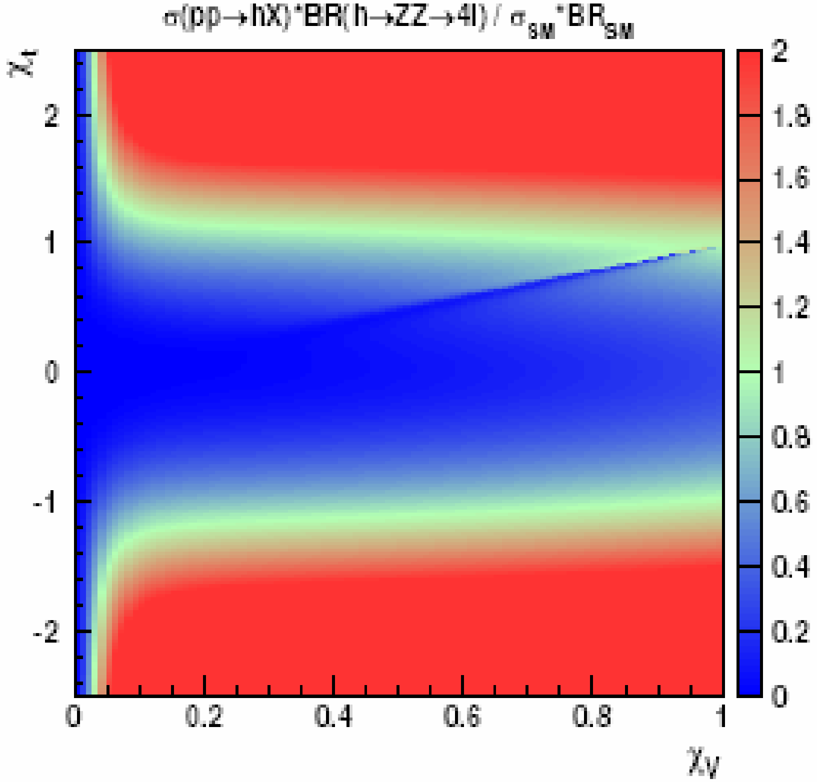
$$\sigma(pp \to hX) \cdot BR(h \to ZZ \to 4l)$$

"golden channel"

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

Precision ~ 20% expected

Cross section relative to SM

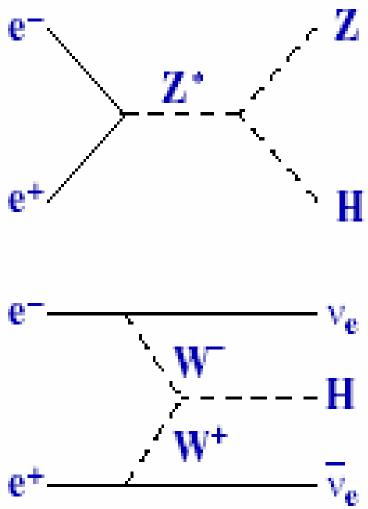


ILC

For Higgs boson production at TESLA

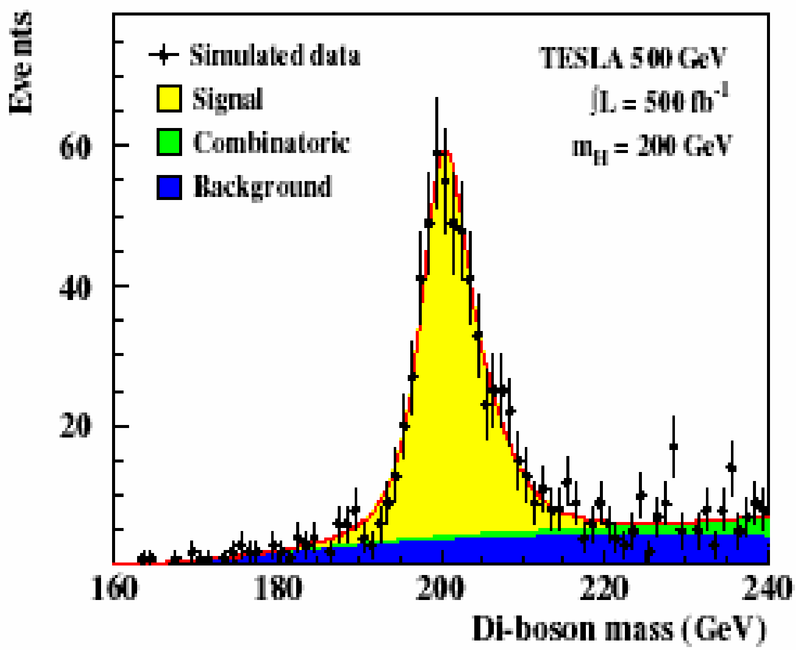
($\sqrt{s} = 500\ GeV$, 500 fb^{-1})

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

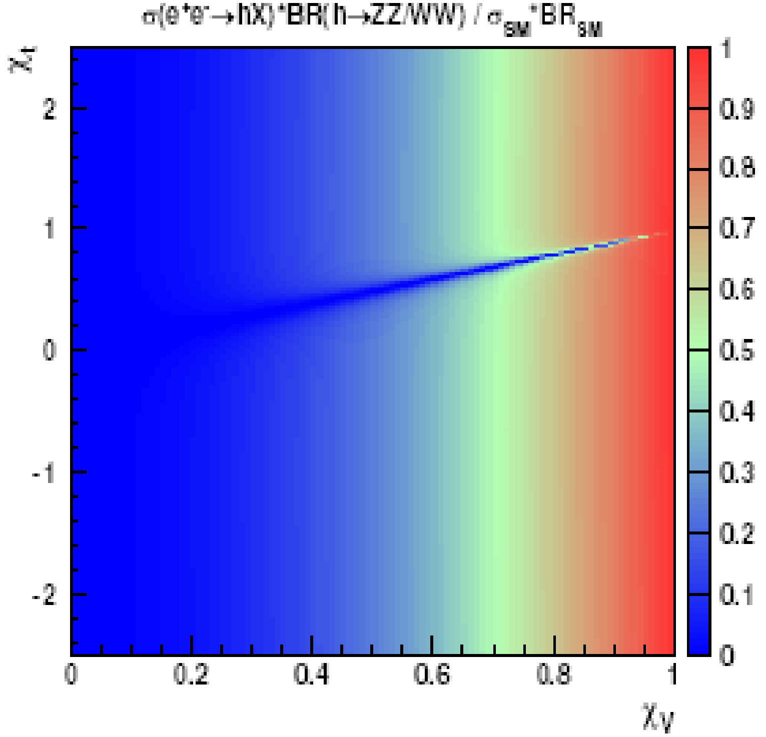
Measurement of the production cross section times branching ratio

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

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

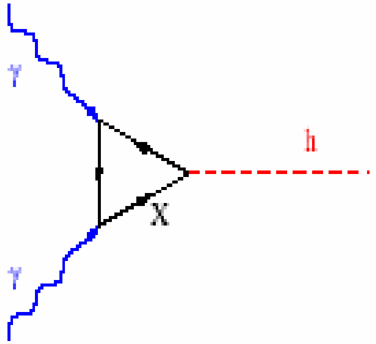
This will constrain the χ_V value

Cross section relative to SM



PLC

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



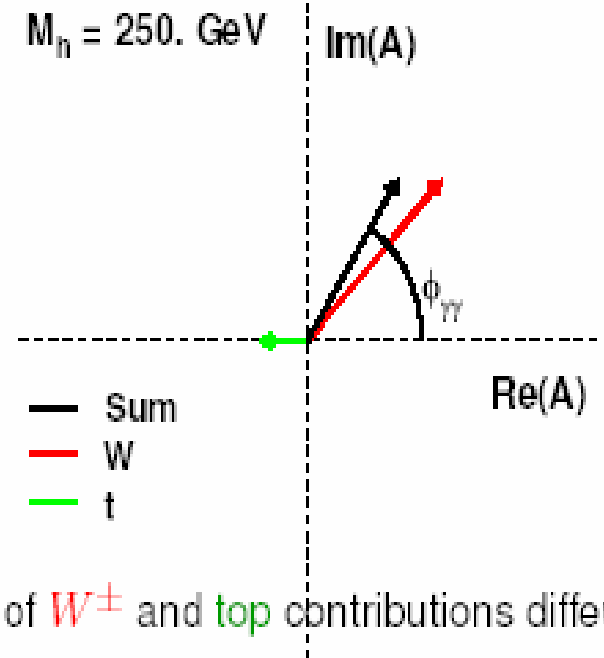
$$\Gamma(h \to \gamma\gamma) \;=\; \frac{G_F \alpha^2 M_h^3}{128\sqrt{2}\,\pi^3} \cdot |\mathcal{A}|^2$$

where:

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

two-photon amplitude

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



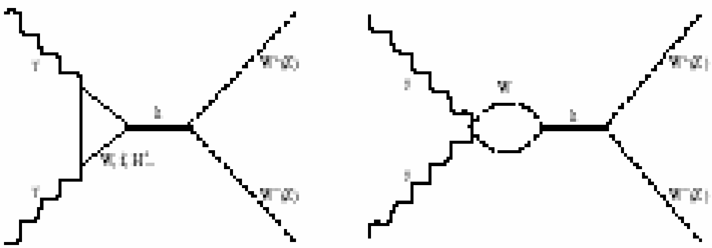
Phases of $W^\pm$ and top contributions differ

Phase of top distribution changes with Φ_{HA} !

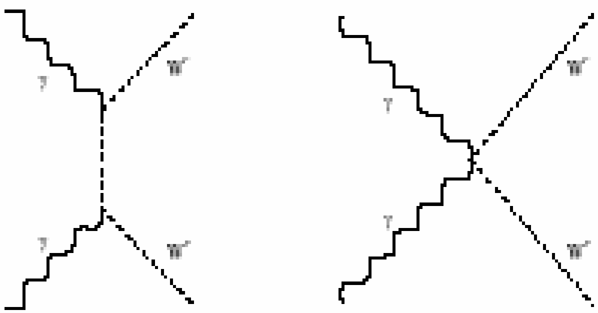
$\Rightarrow$ Both $\Gamma_{\gamma\gamma}$ and the phase of the amplitude $\phi_{\gamma\gamma}$ depend on χ_V and χ_t

PLC

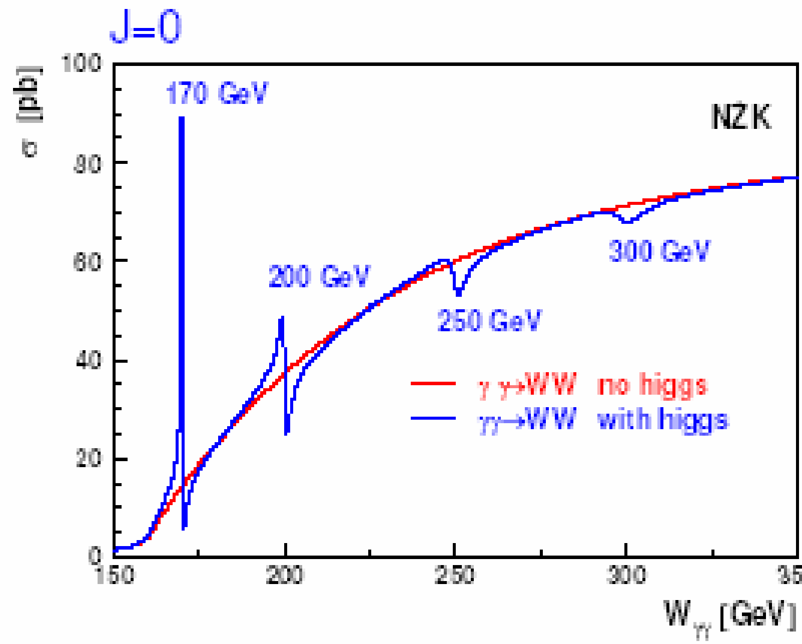
For resonant $\gamma\gamma \to h \to W^+W^-$ signal



here 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

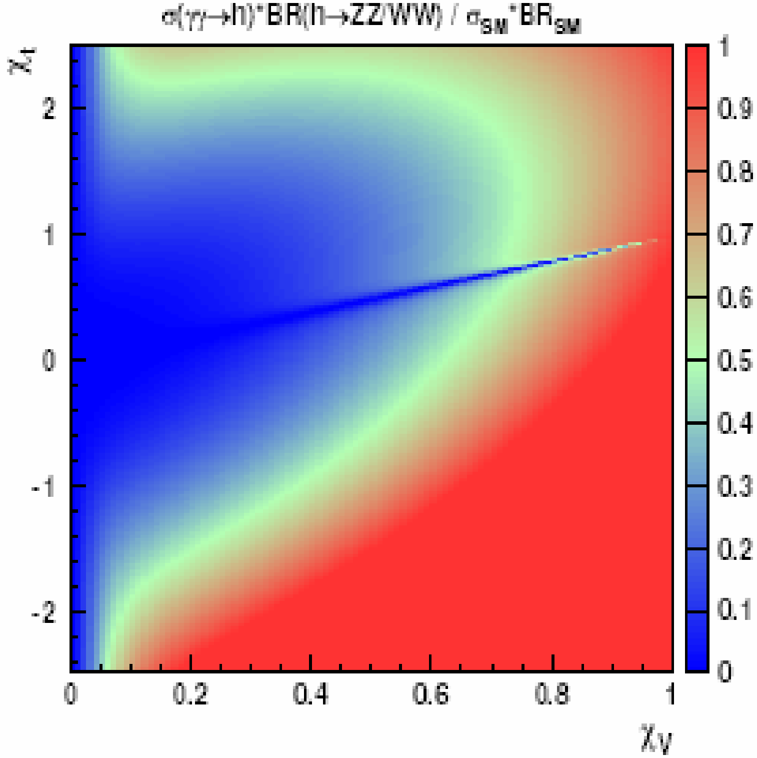
$\sigma(\gamma\gamma \to h) \cdot BR(h \to WW/ZZ)$

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]

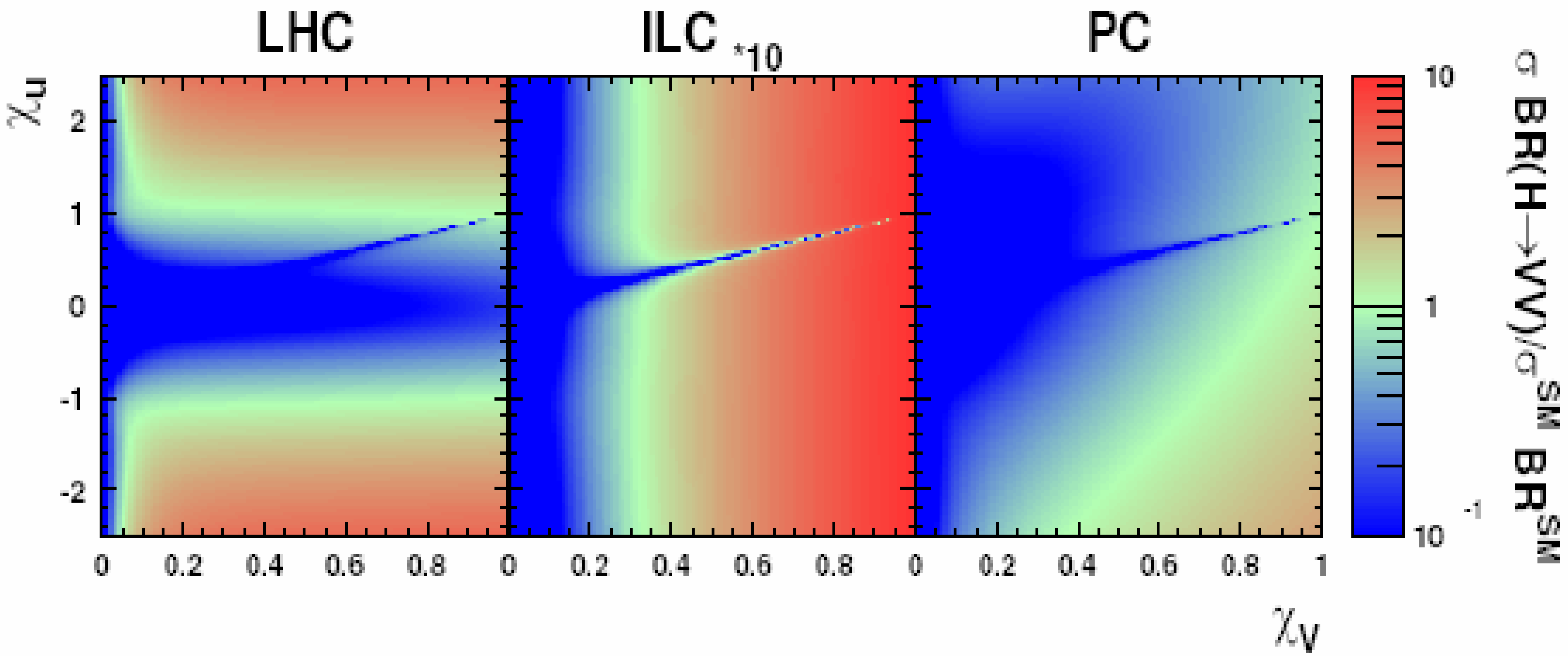
Cross section relative to SM



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 $\qquad M_H = 250 GeV$



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

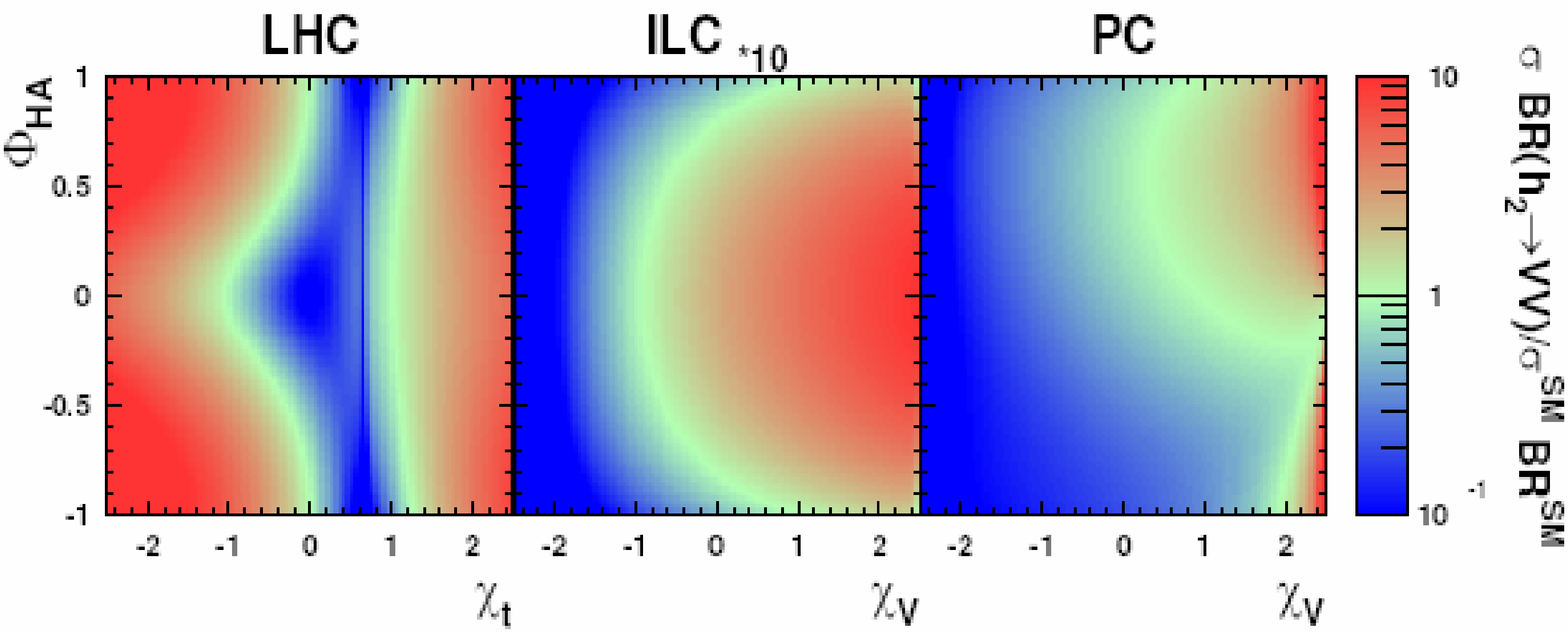
combined analysis of LHC, Linear Collider and Photon Collider data is needed

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

LHC ⊕ ILC ⊕ PC

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

Cross sections × BR relative to SM $\quad M_H = 250 GeV$



Generic model

Couplings

We consider model with a generic tensor couplings of a Higgs boson $\mathcal{H}$, to ZZ and W^+W^-:

$$g_{\mathcal{H}ZZ} = ig\frac{M_Z}{\cos\theta_W}\left(\lambda_H \cdot g^{\mu\nu} + \lambda_A \cdot \varepsilon^{\mu\nu\rho\sigma}\frac{(p_1+p_2)_\rho\,(p_1-p_2)_\sigma}{M_Z^2}\right)$$

$$g_{\mathcal{H}WW} = igM_W\left(\lambda_H \cdot g^{\mu\nu} + \lambda_A \cdot \varepsilon^{\mu\nu\rho\sigma}\frac{(p_1+p_2)_\rho\,(p_1-p_2)_\sigma}{M_W^2}\right)$$

Standard Model (scalar) couplings are reproduced for $\lambda_H = 1$ and $\lambda_A = 0$.

Pseudoscalar Higgs boson corresponds to $\lambda_H = 0$ and $\lambda_A = 1$.

We consider small CP violation (deviations from SM), i.e. $\lambda_H \sim 1$, $|\lambda_A| \ll 1$

$\mathcal{H}$ couplings to fermions assumed to be the same as in the Standard Model.

Model: S.Y. Choi, D.J. Miller, M.M. Mühlleitner and P.M. Zerwas, hep–ph/0210077;
D.J. Miller, S.Y. Choi, B. Eberle, M.M. Mühlleitner and P.M. Zerwas, Phys. Lett. B505 (2001) 149;
D.J. Miller, *Spin and Parity in the HZZ vertex*, ECFA/DESY meeting, Prague, November 2002.

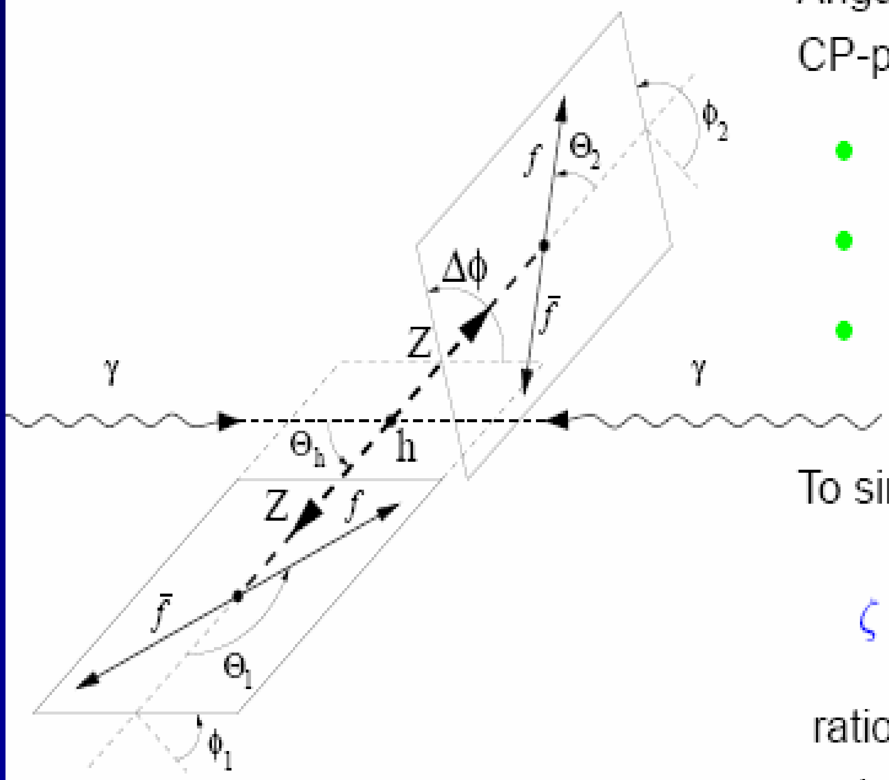
Higgs CP from $\mathcal{H} \to \tau^+\tau^-$: K. Desch, A. Imhof, Z. Was, M. Worek, hep-ph/0307331;
K. Desch, Z. Was, M. Worek, Eur.Phys.J.C29 (2003) 491, hep-ph/0302046.

Higgs CP from $\mathcal{H} \to t\bar{t}$: E. Asakawa, K. Hagiwara, hep-ph/0305323.

Godbole at al. tt/ττ

Generic model

Angular distributions



Angular variables used in the analysis of higgs CP-properties:

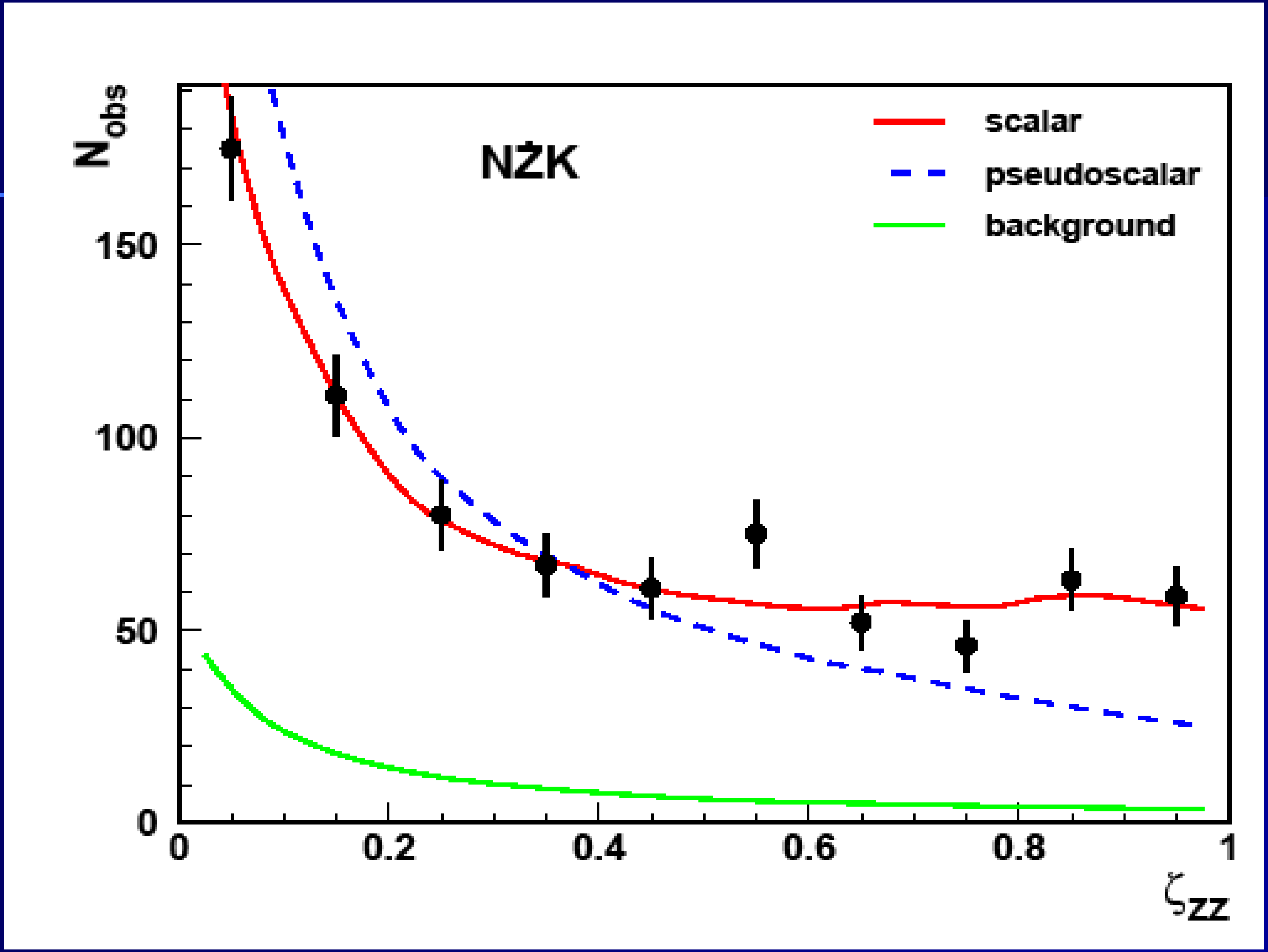
- higgs decay angle angle Θ_h
- polar angles Θ_1 and Θ_2
- angle between two Z/W decay planes, $\Delta\phi = \phi_2 - \phi_1$

To simplify the analysis, we introduce

$$\zeta = \frac{\sin^2\Theta_1 \cdot \sin^2\Theta_2}{(1+\cos^2\Theta_1)\cdot(1+\cos^2\Theta_2)}$$

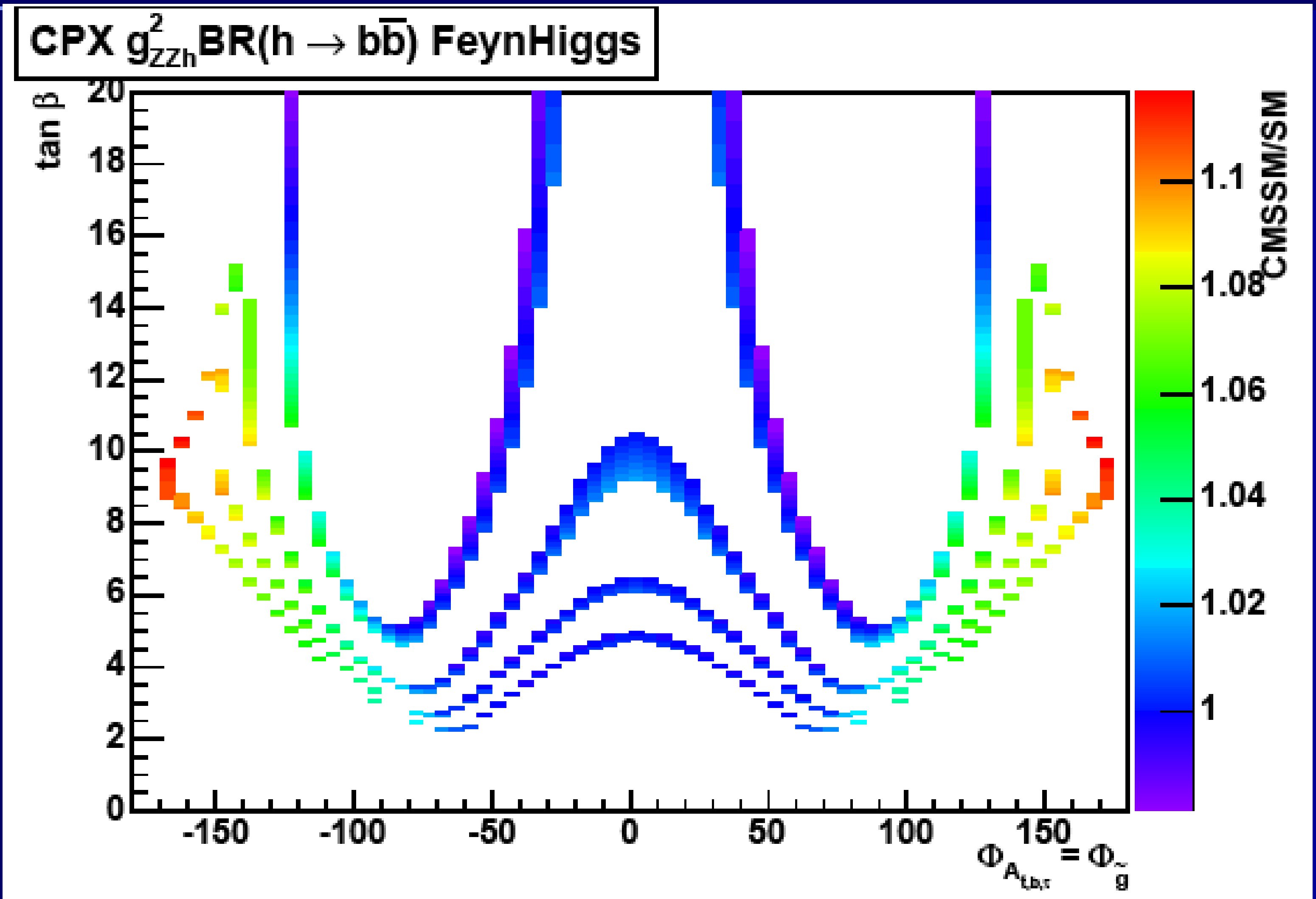
ratio of the distributions expected for a scalar and a pseudoscalar higgs (for $M_h \gg M_Z$).

All polar angles are calculated in the rest frame of the decaying particle.



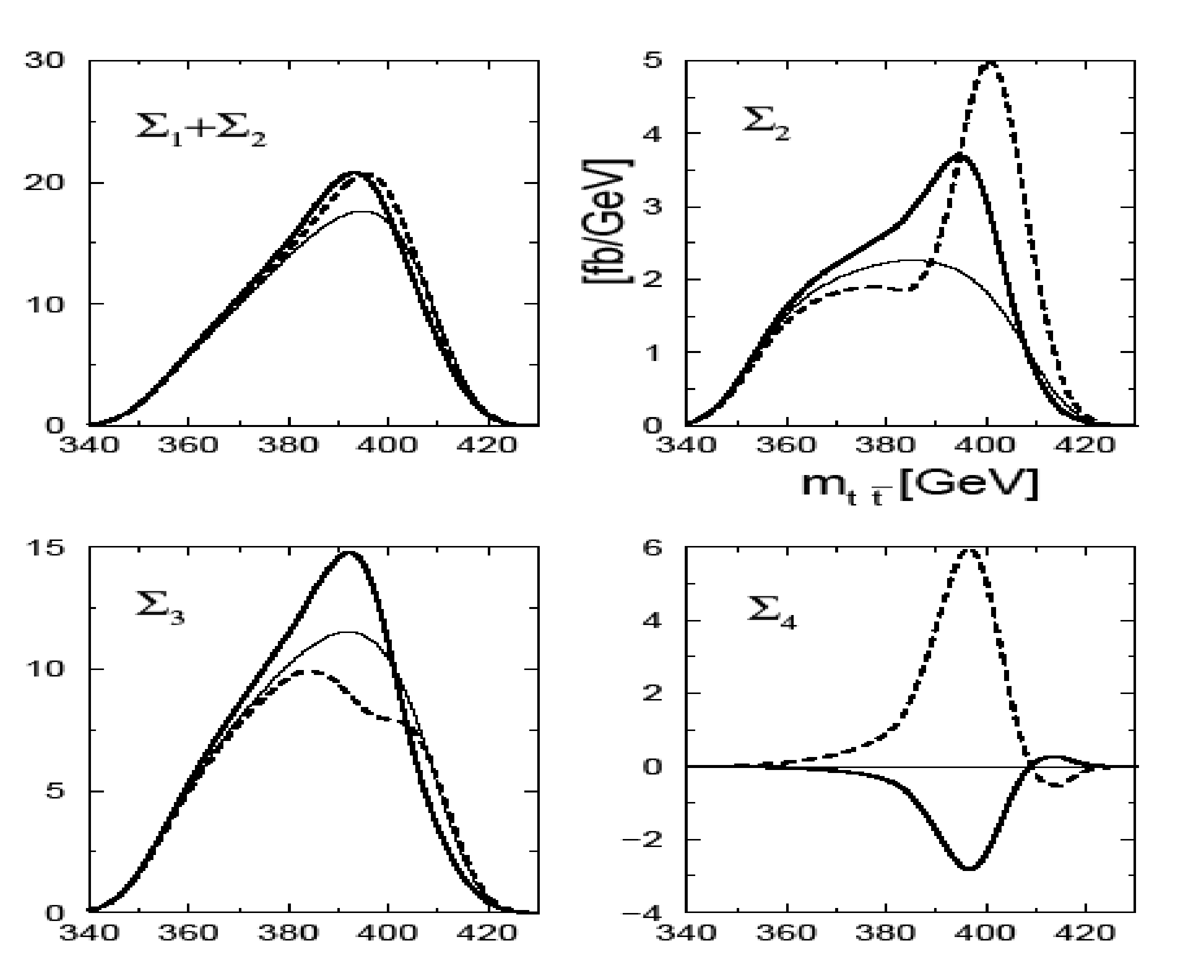
NŻK
scalar
pseudoscalar
background
N_{obs}
ζ_{ZZ}
0
50
100
150
0
0.2
0.4
0.6
0.8
1

ZZh – CPX (mass) Henemeyer, Velasco 2005



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

Asakawa, Hagiwara..



Scalar (dashed)

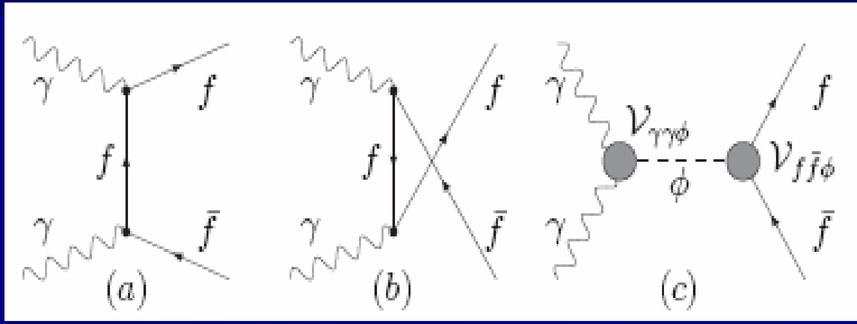
Pseudoscalar (thick solid)

Mass – 400 GeV

Probing the CP-violating Higgs contribution in $\gamma\,\gamma \to$ ff; Godbole, Kraml, Rindani, Singh – Phys. Rev. D (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

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

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

ff democratic CP-even and CP-odd coupling

In contrast to VV case – typically A_V dominates

Higgs physics at PLC

- Precision measurements of light H (->bb) Jikia,Gunion
- Distinguishing SM-like scenarios Ginzburg,Gunion
- Establishing CP property of Higgs bosons

  Grzadkowski,Godbole,Zerwas,Kalinowski

  Heinemeyer, Asakawa,Ellis,Pilaftsis,Lee
- Covering LHC wedge Spira,Muhlleitner, Kramer,Zerwas,Gunion Niezurawski,MK
- Testing Higgs selfinteraction Kanemura, Okada,Belusevic
- Determination of tan beta in $\tau^+\tau^-$ fusion

  Zerwas,Kalinowski
- Testing non-standard scenarios

Signal and background

Table 1: Total cross sections for the process $\gamma\gamma \to e^+e^-G_n$, with and without photon polarization. M_S is set to be 1 TeV, the polarization efficiency $P_\gamma = 0.9$, and the cross sections are in fb.

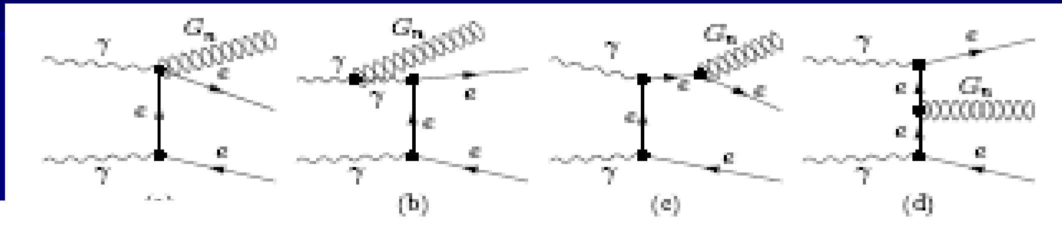
$\sqrt{s}$ [GeV]		$\delta = 3$	$\delta = 4$	$\delta = 5$	$\delta = 6$
500	unpol.	46.46	13.92	4.692	1.700
	$+-$	60.01	19.35	6.853	2.576
	$++$	32.91	8.493	2.532	0.821
1000	unpol.	371.7	222.7	150.1	108.8
	$+-$	480.8	309.6	219.3	164.9
	$++$	262.6	135.8	80.93	52.75

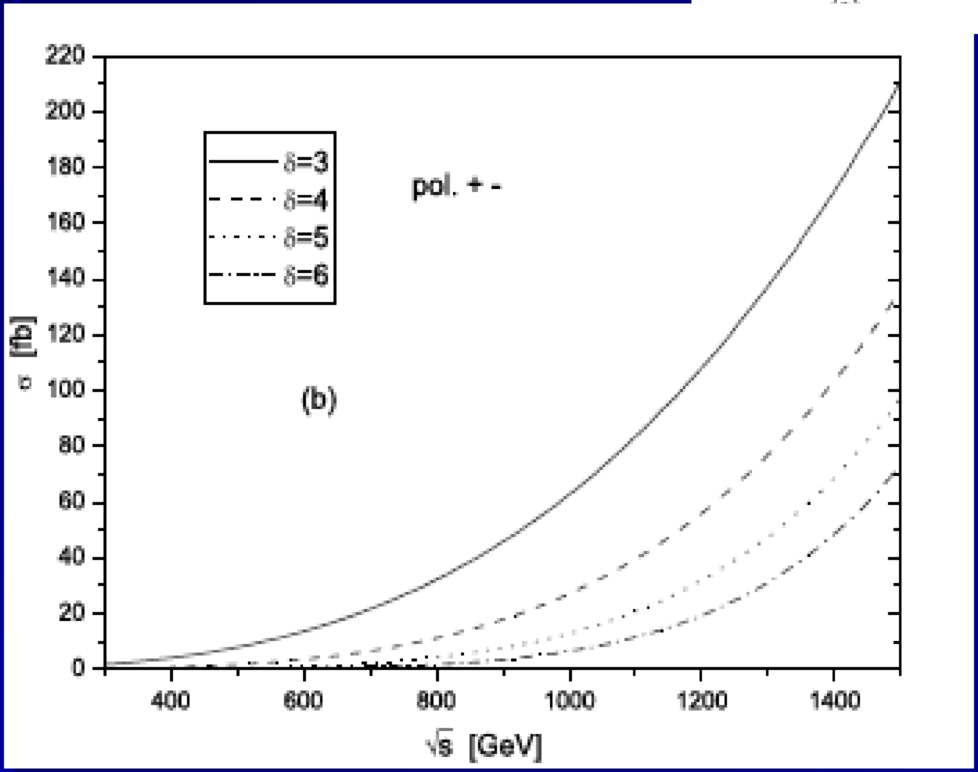
Full bakground simulation

We conclude that by adopting an unpolarized $\gamma\gamma$ collision machine with $\sqrt{s} = 1$ TeV in the case of $\delta = 3$ and $\mathcal{L} = 100 fb^{-1}$, the graviton signal can be detected when $M_S \lesssim 2.67$ TeV, while in the case of $\sqrt{s} = 500$ GeV, the graviton signal can be detected only when $M_S \lesssim 1.40$ TeV. If we adopt a $\gamma\gamma$ collider machine in $+-$ polarized photon collision mode, the detecting upper limits on the fundamental scale can be improved up to 2.79 TeV when $\sqrt{s} = 1$ TeV, and 1.44 TeV when $\sqrt{s} = 0.5$ TeV.

Using lum process to detect KK graviton in ADD at PLC ; Zhou,Ma,Han,Zhang hep-ph/07081195

- $\gamma\gamma \to e^+e^-G_n$





For J=2 large cross section

Polarization efficiency

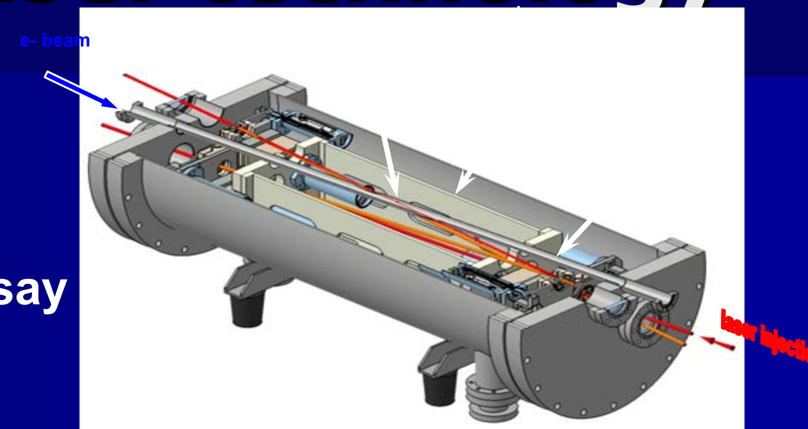
$P_\gamma=(N_+-N_-)/(.+.)$

Fund. scale M_s=1.5 TeV

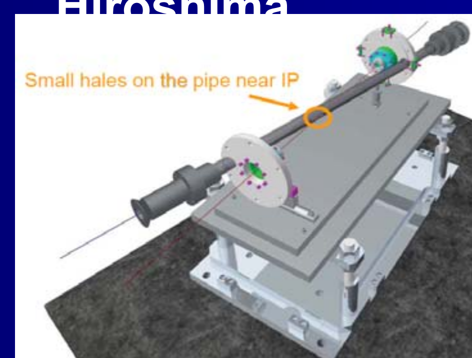
Golden processes	PLC2000 proc.
$\gamma\gamma \to H, h \to b\bar{b}$	SM/MSSM Higgs, $M_{H,h} < 160$ GeV
$\gamma\gamma \to H \to WW(^*)$	SM Higgs, 140$< M_H <$ 190 GeV
$\gamma\gamma \to H \to ZZ(^*)$	SM Higgs, 180$< M_H <$ 350 GeV
$\gamma\gamma \to H \to \gamma\gamma$	SM Higgs, 120$< M_H <$ 160 GeV
$\gamma\gamma \to H \to t\bar{t}$	SM Higgs, $M_H >$ 350 GeV
$\gamma\gamma \to H, A \to b\bar{b}$	MSSM heavy Higgs, interm. tan β
$\gamma\gamma \to H^+H^-$	large cross sections
$\gamma\gamma \to \tilde{f}\bar{\tilde{f}},\ \tilde{\chi}_i^+\tilde{\chi}_i^-$	large cross sections
$\gamma\gamma \to \tilde{g}\bar{\tilde{g}}$	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

Compton light sources are developing the laser technology

LAL - Orsay



KEK - Hiroshima



- Resonant cavities are being developed for:
  - Polarized positron source
  - Laser wire
  - Beam diagnostics
  - Medical and industrial applications

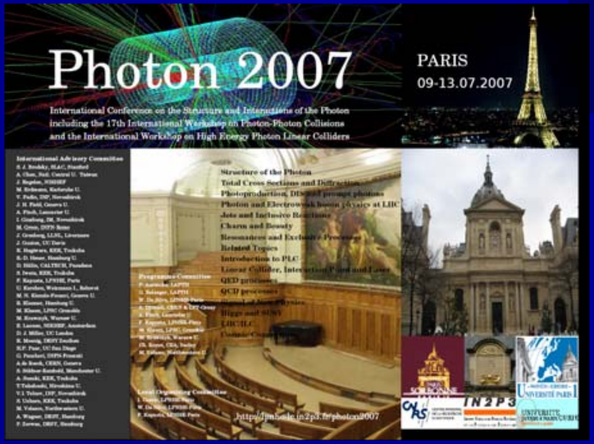
Laser development is being pushed by applications inside and outside of HEP

Other PLC related conferences and workshops 2007/8

- **Photon 2007 Paris in July**
  - **Workshop on photon linear colliders and physics of photon-photon collisions**
- **Hiroshima workshop on intense laser electron beam interactions, Dec 2007**

http://home.hiroshima-u.ac.jp/lei2007/

- **Posipol 2008, Hiroshima in May**
  - Laser and resonant cavities for photon beam production



Photon Linear Collider