Physics at a Photon Collider

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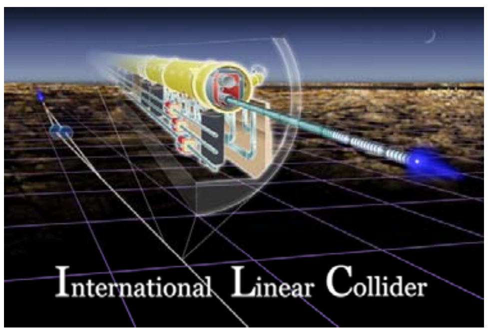
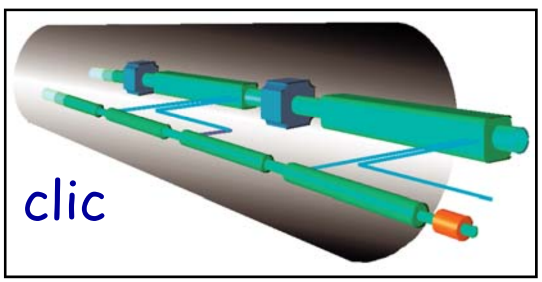
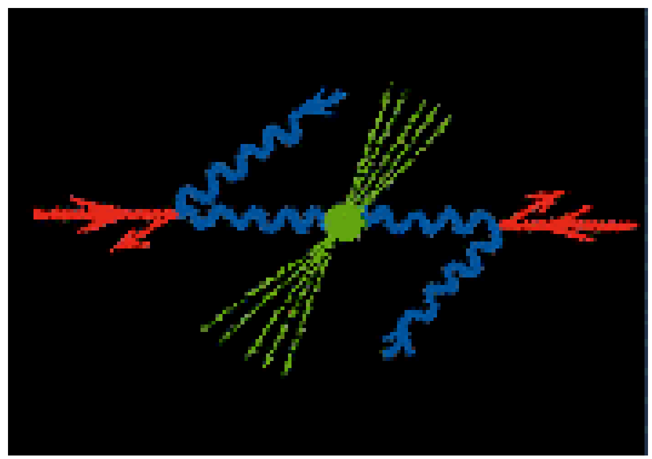
CERN

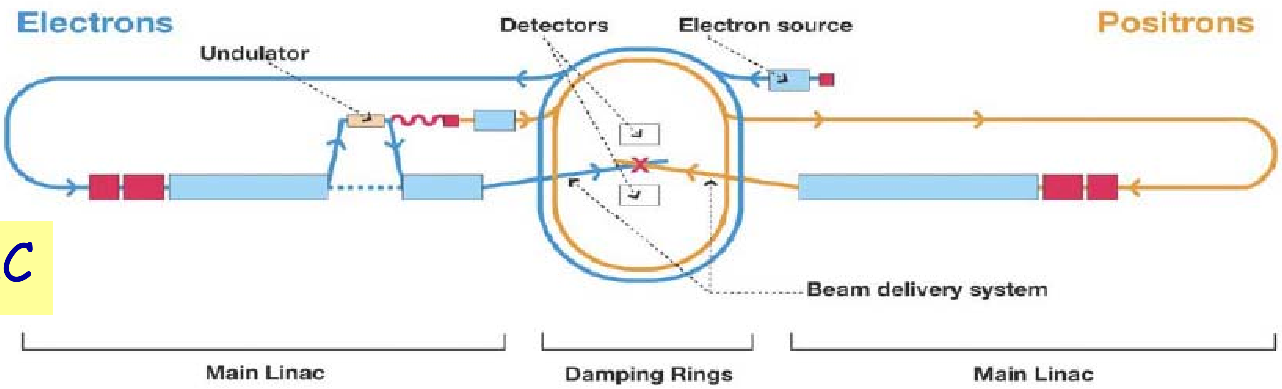
CERN April 2008







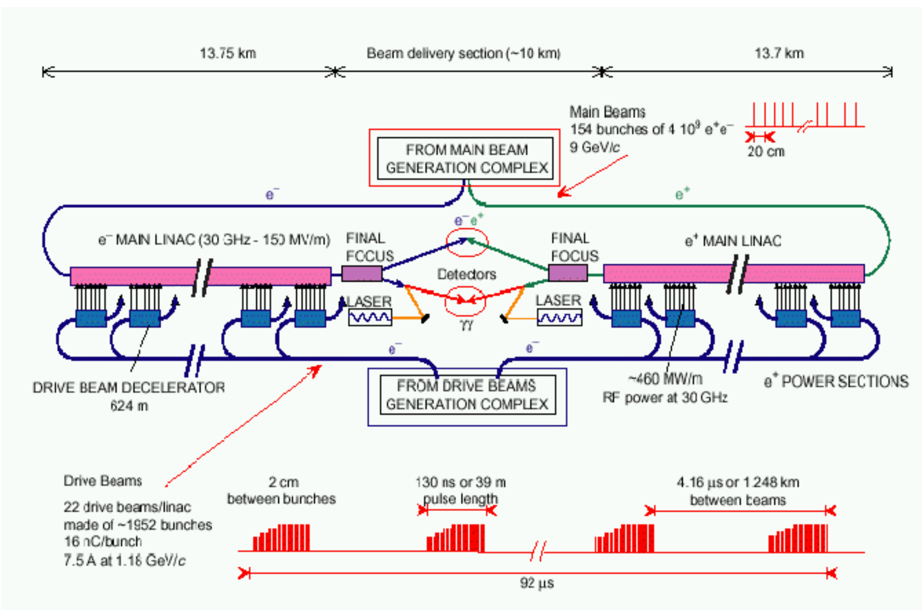
Linear Colliders



ILC

Luminosity
~ $2\bullet10^{34}$ $cm^{-2}s^{-1}$

~31 km (500 GeV)

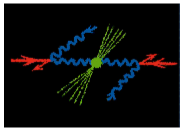


CLIC

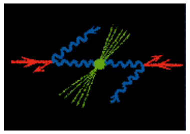
Luminosity
~ $6\bullet10^{34}$ $cm^{-2}s^{-1}$

~41 km (3000 GeV)

Both can have a PLC mode



Contents



- Introduction: Kinematics, luminosity spectra
- QCD studies: photon structure
- Higgs production at a photon collider: SM and beyond the SM
- Supersymmetry
- W-boson interactions
- Extra Dimensions
- Top Quark

Further reading: B. Badelek et al., TESLA TDR part VI appendix
E. Boos et al., hep-ph/0103090
Proceedings of the ECFA/DESY '01-'03 workshop.
hep-ph/0308103, hep-ph/0311138/hep-ph/0307175 80 83
PLC05 proceedings, LCWS07 and Photon2007 proceedings

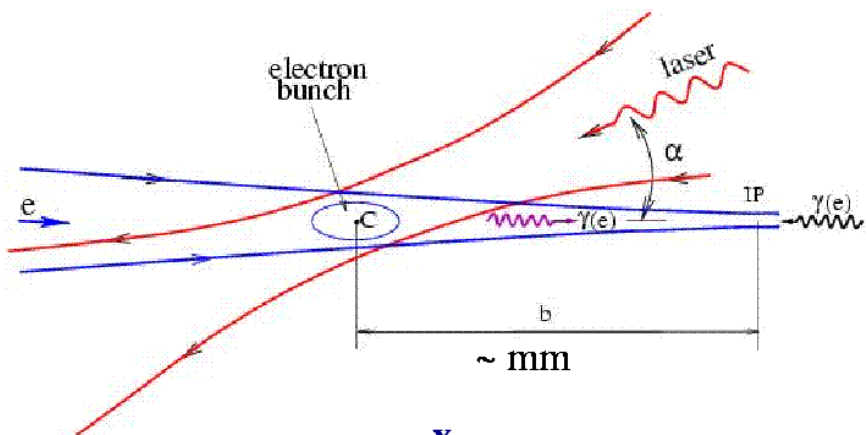
Took some slide from M. Krawczyk from LEI2007 (Dec 2007)

Two-photon interactions

Two ways to have two photon interactions at linear colliders

- Weizacker-Williams spectrum from electron beams, similar to LEP
- Convert electron beams into photon beams by Compton backscattering of laser photons ⇒ high energy $\gamma\gamma$ & high luminosity

Luminosity Spectrum of a Photon Collider



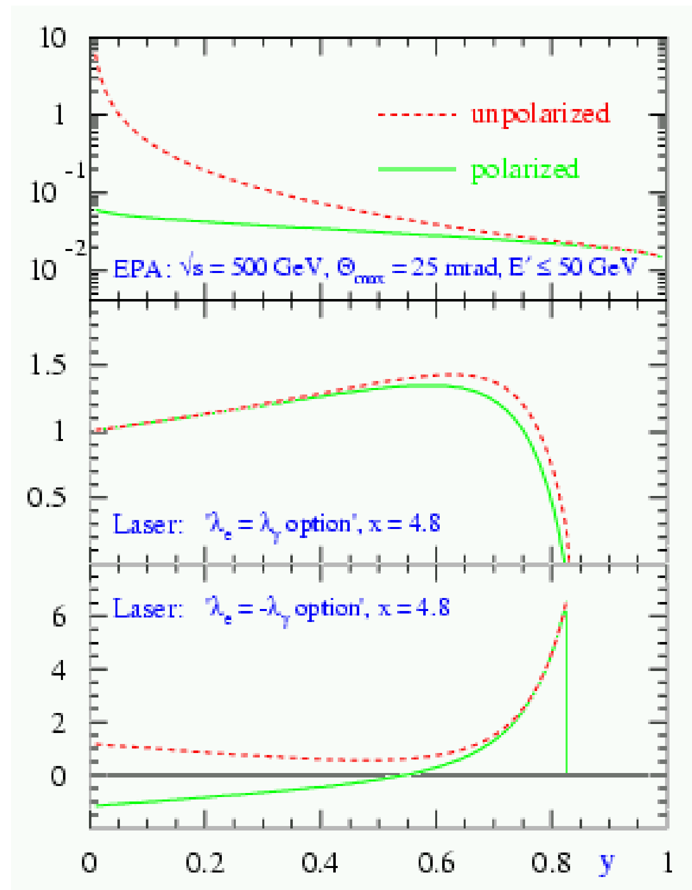
$$E_\gamma^{max} = \frac{x}{x+1} E_e$$

$$x = \frac{4 E_\gamma^0 E_e}{m_e}$$

$$E_e = 250\,GeV;\, E_\gamma^0 = 1.17\,eV\,(\lambda = 1.06\,\mu m) \Rightarrow$$

$$x = 4.5 \wedge E_\gamma^{max} = 0.82\, E_e$$

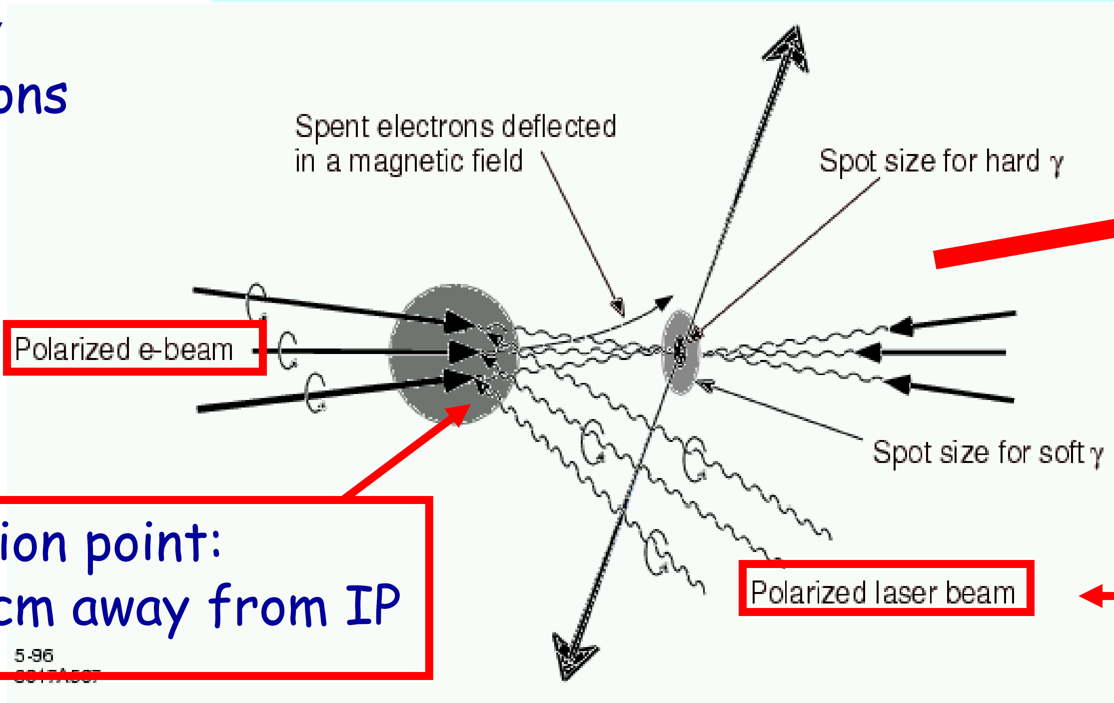
V.Telnov et al.



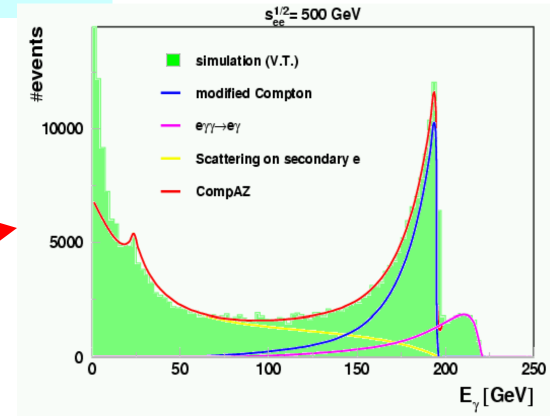
A Photon Collider

convert electron beams into photon beams

γγ or eγ interactions



Conversion point:
1 mm-1 cm away from IP



Shoot photons from a laser onto the electron beam

Compton backscattering on low energy (eV) laser photons

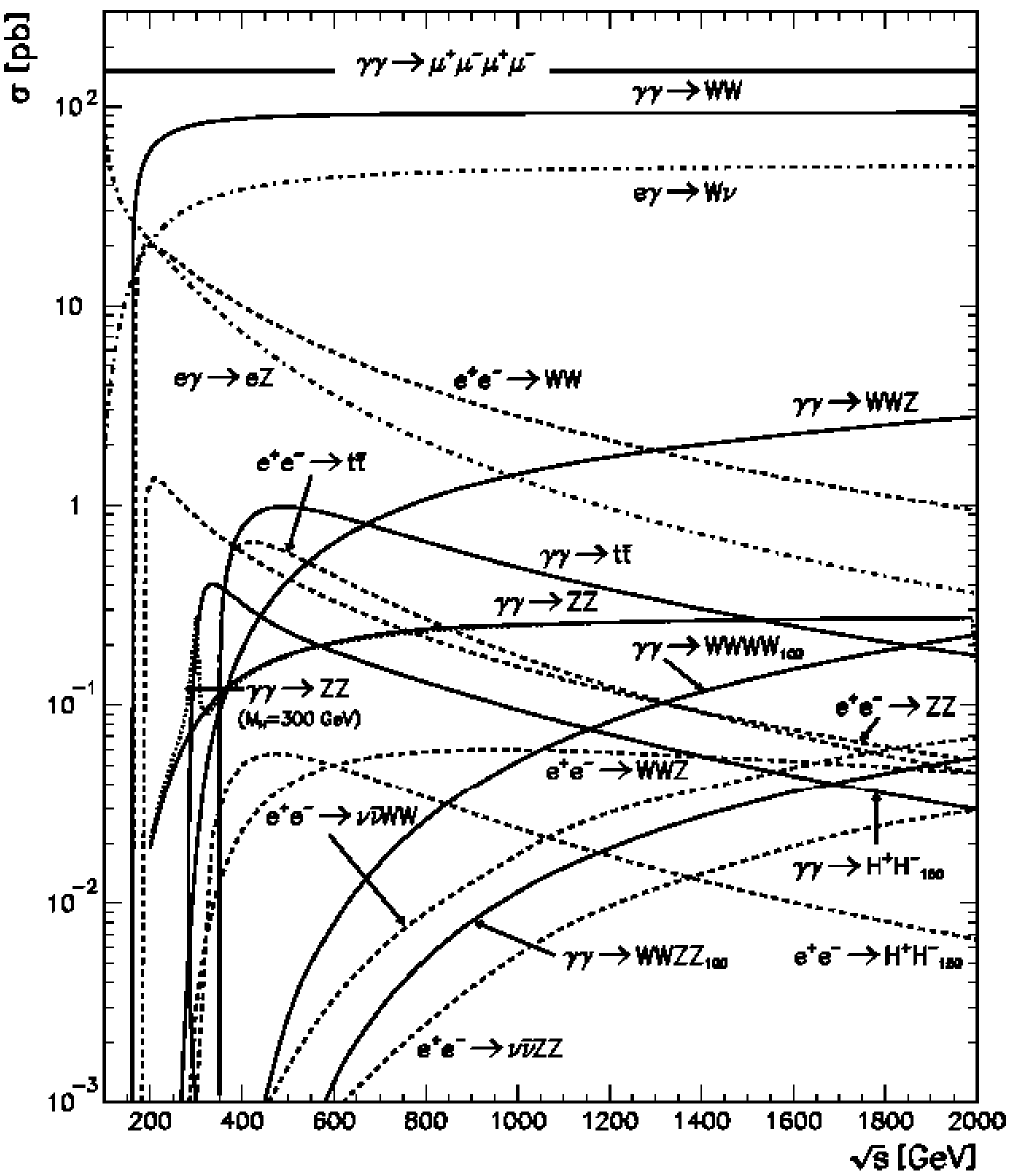
- Needs crossing angle (to avoid background from disrupted beams)
- Needs second interaction point (lasers, optics)
- Needs only e- beams (no positrons)

  ⇒ higher polarization (electrons 80% vs positrons 40-60%)

Physics at a $\gamma\gamma$ and $e\gamma$ collider

General

Cross sections for γγ processes



Historically:

The Photon Collider (PLC)
Ginzburg, Kotkin, Serbo, Telnov, Pizma ZhETF 34 514 (1981),JETP Lett. 34 491 (1982)
where the basic ideas have been elaborated

Since then:

- Over 1000 papers on physics issues of a PC
- Taken up seriously in LC studies R&D (slowly) progressing

PLC part of LC roadmap
considered as possible upgrade for a Linear Collider (Jeju 2002)

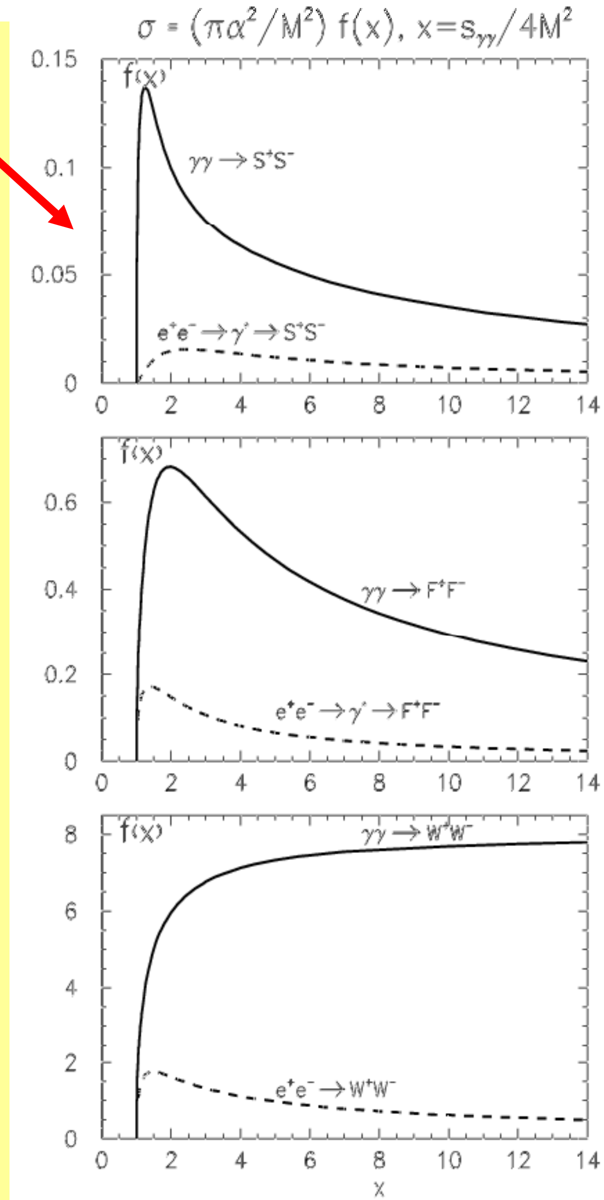
Advantages of γγ and eγ

Higher cross sections for charged particles

- Different J^{PC} state than in e+e-
- Higgs can be s-channel produced
- Higher mass reach in some channels
- Pure QED interaction (in e+e- also Z exchange)
- Higher polarization of initial state (>80%/beam)
- CP analysis opportunities (linear γ polarization…)

⇒ Physics Menu … as for an e+e- collider

- Higgs
- Supersymmetry
- Alternative theories (extra dimensions, etc.)
- EW: e.g. Triple Gauge couplings, QCD, Top,…



Golden Processes for a Photon Collider

Reaction	Remarks	
$\gamma\gamma \to H, h \to bb$	SM/MSSM Higgs, $M_{H,h} < 160$ GeV	Higgs
$\gamma\gamma \to H \to WW(*)$	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	
$\gamma\gamma \to H, A \to bb$	MSSM heavy Higgs, interm. $\tan\beta$	
$\gamma\gamma \to \tilde{f}\bar{\tilde{f}},\ \tilde{\chi}_i^+\tilde{\chi}_i^-$	large cross sections	SUSY
$\gamma\gamma \to \tilde{g}\tilde{g}$	measurable cross sections	
$\gamma\gamma \to H^+H^-$	large cross sections	
$\gamma\gamma \to S[\tilde{t}\bar{\tilde{t}}]$	$\tilde{t}\bar{\tilde{t}}$ stoponium	
$e\gamma \to \tilde{e}^-\tilde{\chi}_1^0$	$M_{\tilde{e}^-} < 0.9 \times 2E_0 - M_{\tilde{\chi}_1^0}$	
$\gamma\gamma \to \gamma\gamma$	non-commutative theories	EDs,...
$e\gamma \to eG$	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	Trilin. coupl.
$e\gamma \to W^-\nu_e$	anom. W couplings	
$\gamma\gamma \to 4W/(Z)$	WW scatt., quartic anom. W,Z	
$\gamma\gamma \to t\bar{t}$	anomalous top quark interactions	Top
$e\gamma \to \bar{t}b\nu_e$	anomalous Wtb coupling	
$\gamma\gamma \to$ hadrons	total $\gamma\gamma$ cross section	QCD
$e\gamma \to e^-X, \nu_eX$	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	

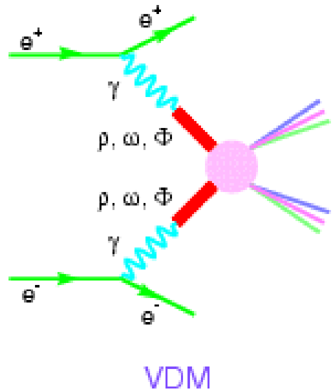
Boos et al.,
hep-ph/0103090

ADR (ECFA/DESY)
hep-ph/0311138

Note: γγ hadronic processes

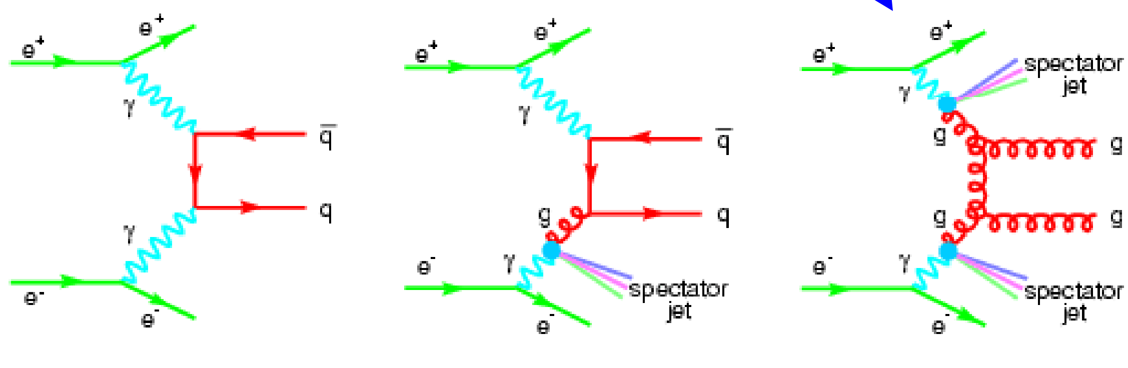
γγ processes

SOFT:



Like hadron-hadron collisions

HARD:



Photon fluctuates in a hadron: γγ→ hadrons

⇒Source for QCD studies

⇒Source of background (can overlay with other events as at LHC)

Physics Processes

QCD

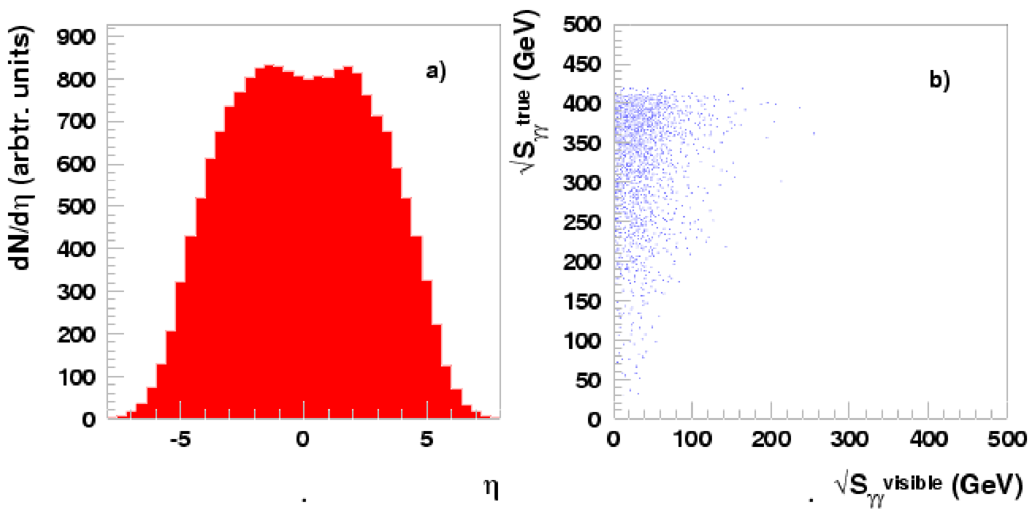
Higgs

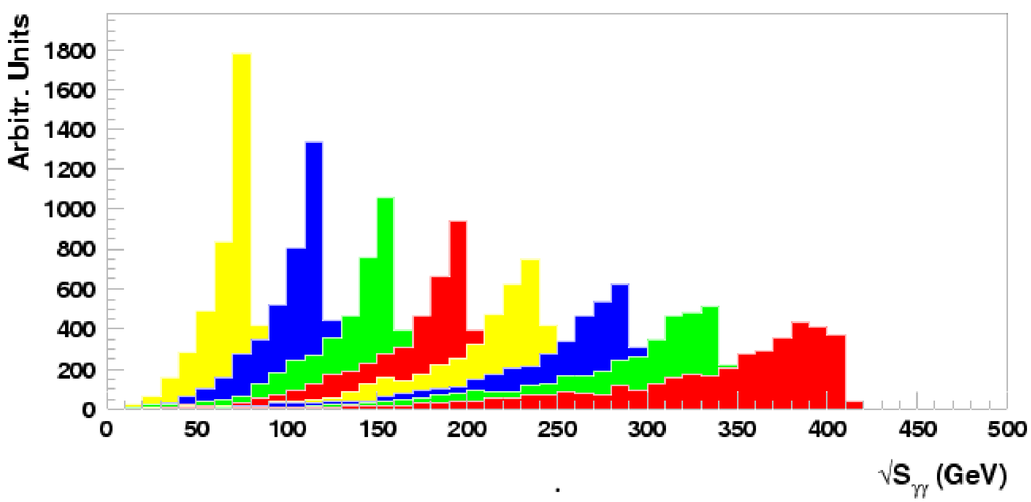
EW

SUSY

Alternatives

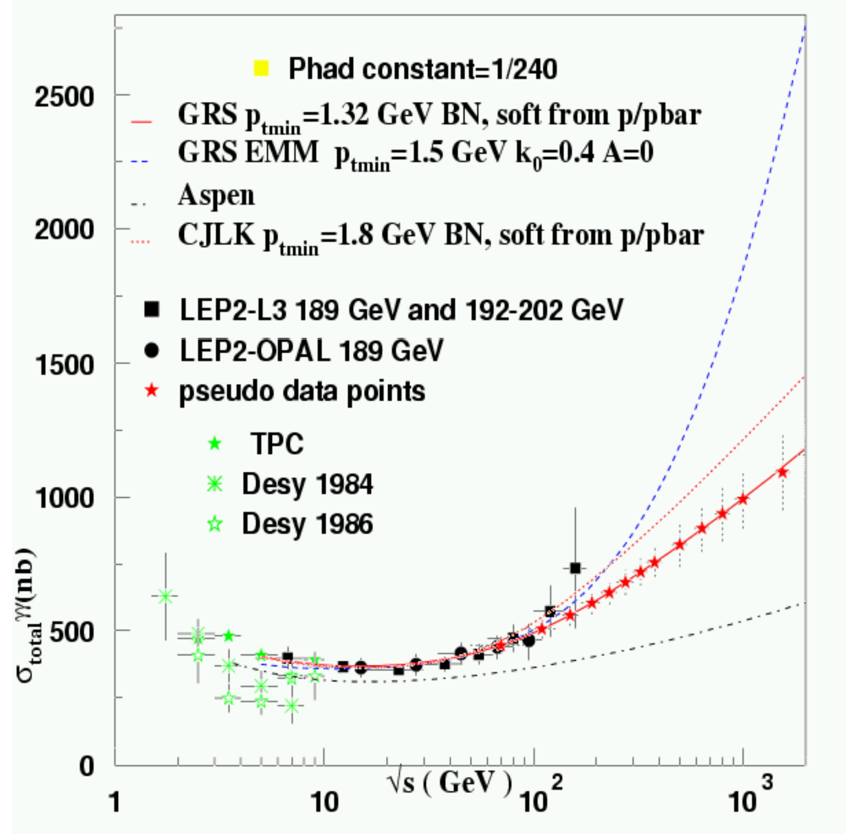
Total Cross Section





Fixed $x = 4.8 \longrightarrow$ change laser energy

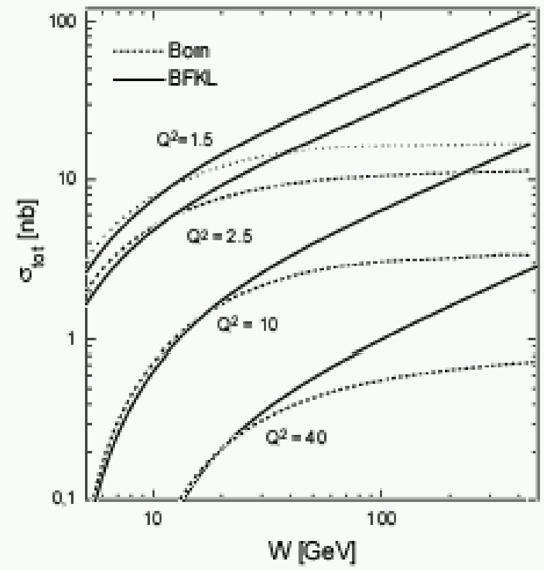
Pancheri, Grau, Godbole, ADR



Detector level study:
Can measure $\sigma(\gamma\gamma)_{tot}$ to 7-15%
at several energies

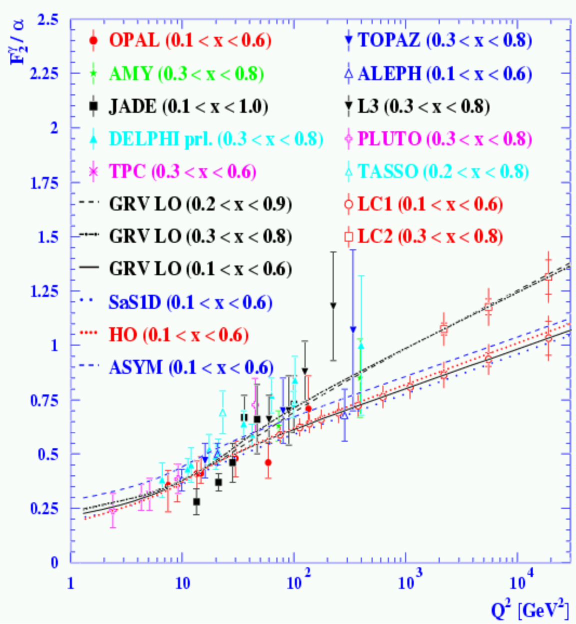
QCD e+e- collider

- What can be done with an e+e- collider
  - Structure of the photon
  - Polarised structure (few points)
  - γγ scattering (jets charm)
  - γγ total cross section (difficult!)
  - γ*γ* total cross section : unique!
  - …But no new physics search



γ*γ* cross section Kwiecinski et al. (and many others)

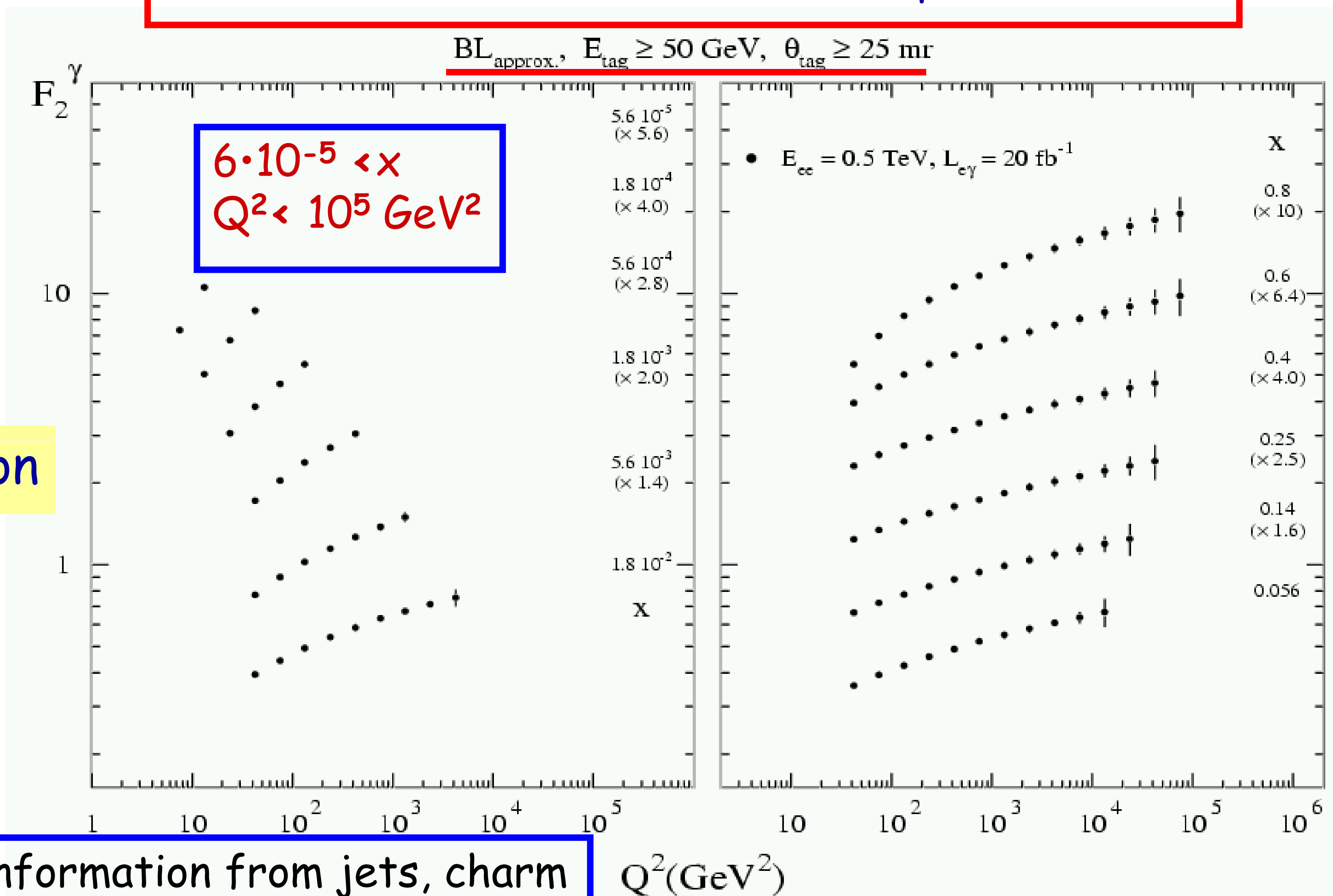
Nisius



$\theta_{min} - \theta_{max}$	$\sigma(e^+e^- \to e^+e^- + hadrons)$ [fb] Born	Hard	Full (LS)	Events / year Full (LS)
10–20	134	365	450	90000
20–30	16	41	46	9200
30–40	3.5	8	9	1800
40–50	1.1	2.3	2.5	500
50–70	0.6	1.1	1.3	260
30–70	5.2	11	13	2600

QCD

Photon structure function reach at a photon collider



$6 \cdot 10^{-5} < x$
$Q^2 < 10^5\ GeV^2$

Vogt & ADR

eγ option

Also information from jets, charm

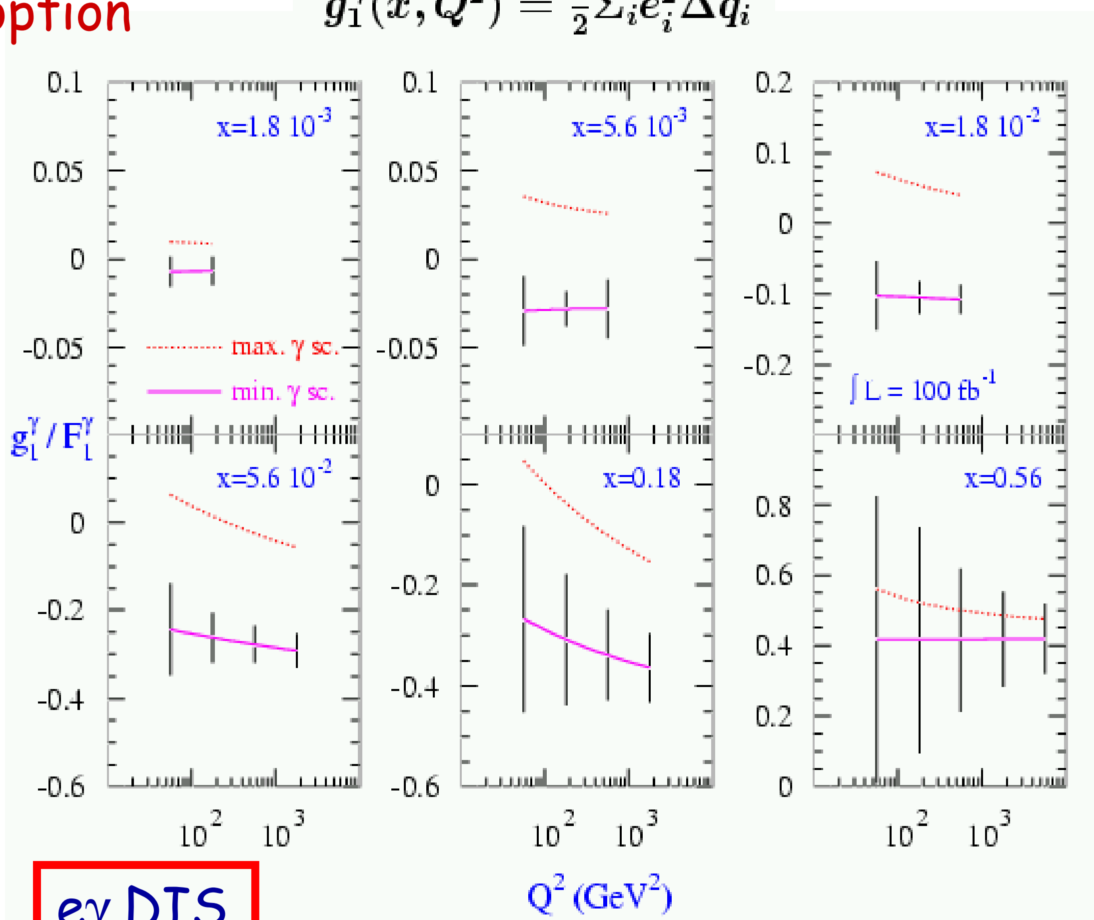
QCD

Unique: the polarised structure of the photon
Use of polarised beams in e+e- or γγ/eγ

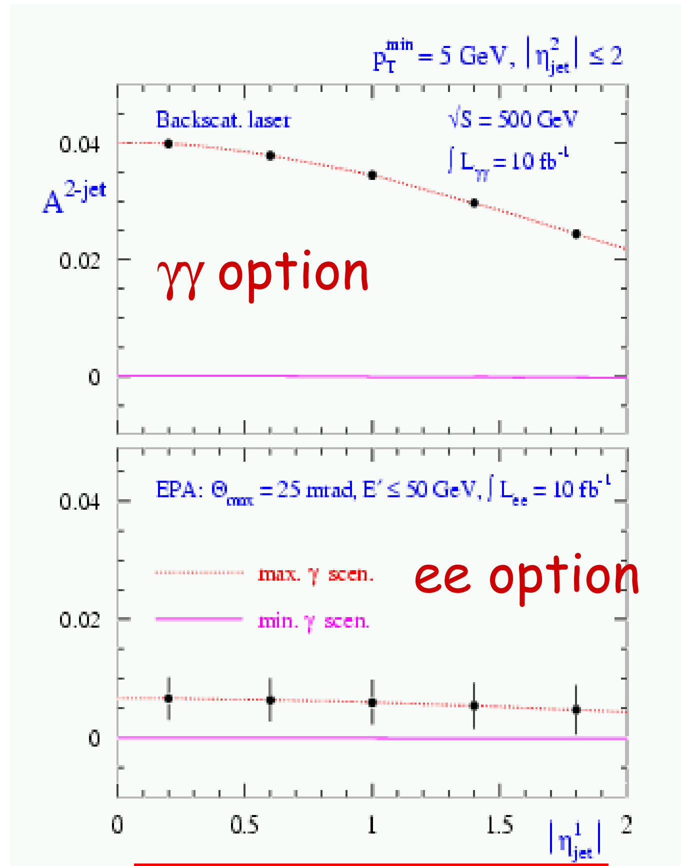
Stratmann and Vogelsang

eγ option

$$g_1^\gamma(x,Q^2) = \frac{1}{2}\Sigma_i e_i^2 \Delta q_i$$



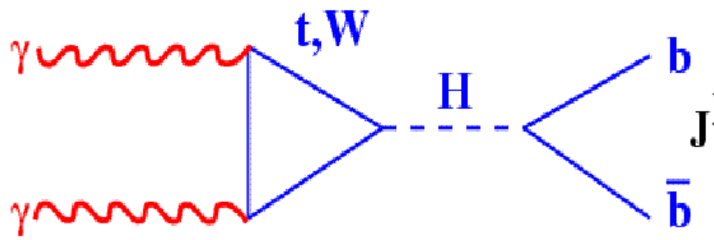
eγ DIS



Jet asymmetries

Higgs

Production Mechanism for Neutral Higgs Bosons



Landau-Yang
$J^{PC}=0^{-+},0^{++},2^{++}$

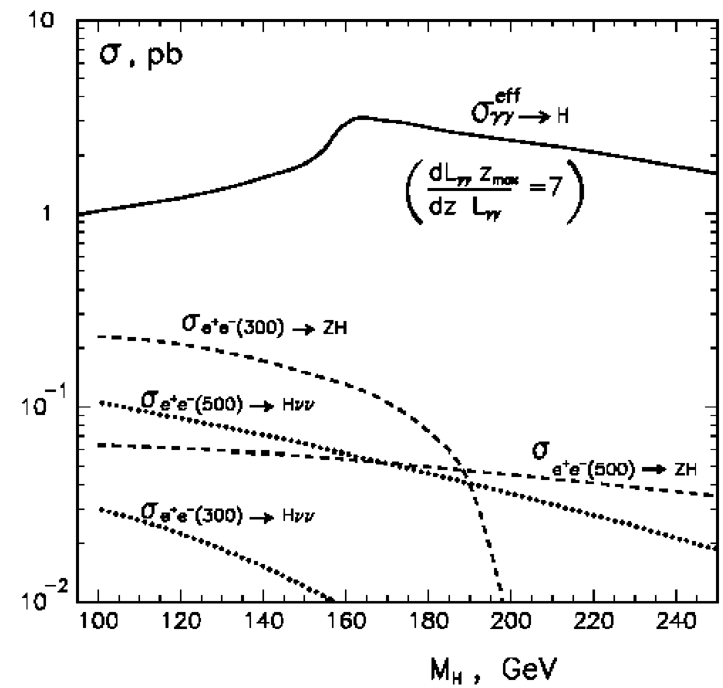
Heralded as THE key measurement for the gamma-gamma option

Higgs produced in the s-channel

Enters only at the loop level
Mainly sensitive to tH and WH couplings

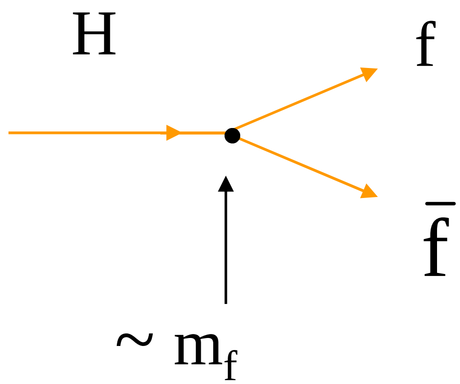
All charged particles (also new, unseen ones) contribute! These will affect the partial width $\Gamma(\gamma\gamma)$

Cross section larger than in e+e-



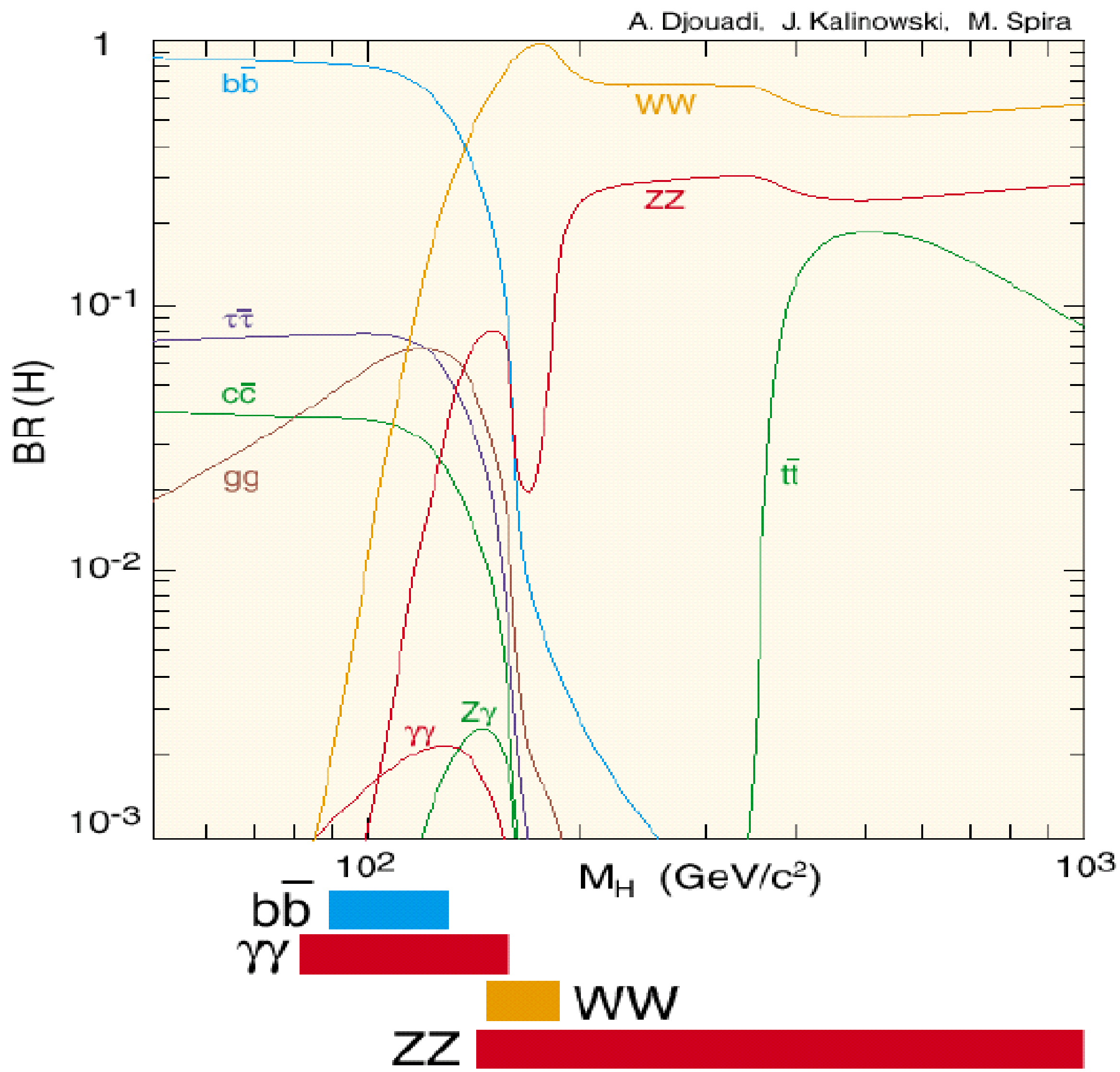
LEP/Tevatron data: SM Higgs M_H > 114 GeV and M_H< ~200 GeV (95 %CL)

Higgs branching ratios



Decay in fermions or gauge bosons

Dominant decay modes:
Low mass: b-quarks
High mass: W's and Z's



Higgs

Suppose Higgs found a the LHC: what would you like to know

- Mass
- Spin & parity
- CP properties/Violation?
- How does it decay
  - Confirm Yukawa-like pattern (allow for up/down differences)
  - Can observe rare decays? ($H \rightarrow \gamma\gamma, \gamma Z, \mu\mu$)?
  - Confirm relations between fermion couplings and gauge couplings
  - Unexpected decay modes? Signs/confirmation of new physics?
  - What is the total width?
  - Are there new production modes ($\gamma\gamma \rightarrow \gamma h$ or Zh)?

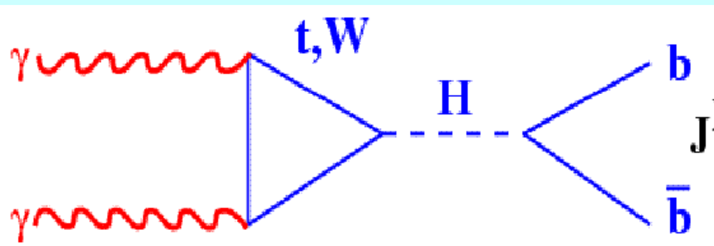
The discovery of an unexpected CP nature of the H would be very exciting

Higgs studies

- Studies on Higgs production at a $\gamma\gamma$ collider
  - Study $H \to$ bb, with realistic spectra, background, B-tagging efficiency,….
  - Study $H \to$ WW, ZZ, $\gamma\gamma$
  - Study model separation power, via the partial width $\Gamma(\gamma\gamma)$
  - Study spin of Higgs in $H \to$ WW,ZZ
  - Study CP properties of the Higgs
  - Study MSSM Higgs (H,A): extend e+e- reach
  - Study of the charged Higgs
  - Study of the Higgs in NMSSM

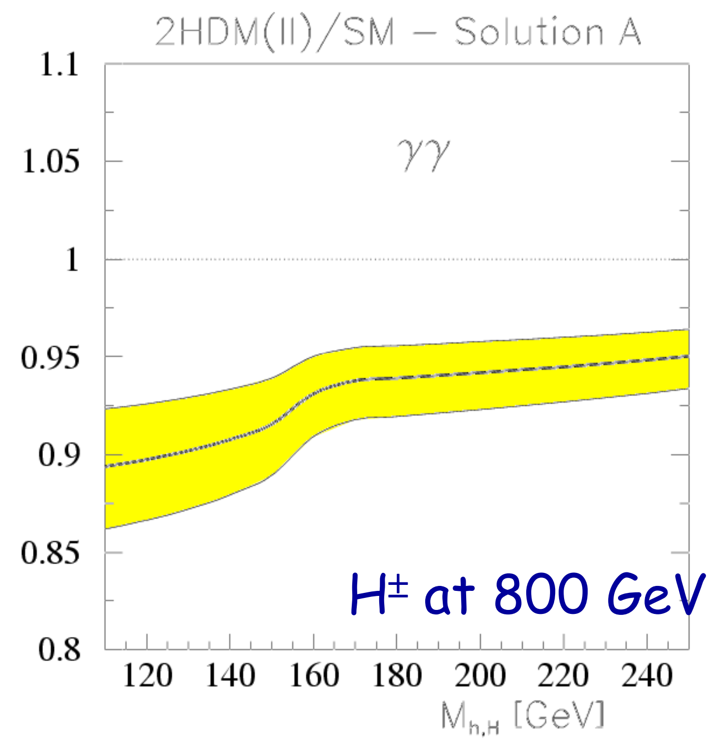
Higgs

The precise measurement of the 2-photon width of the Higgs is very important.
It is affected by all charged particles that can occur in the loop
$\Rightarrow$ Very sensitive to new physics



Landau-Yang
$J^{PC}=0^{-+}, 0^{++}, 2^{++}$

QCD bb in γγ suppression: V. Khoze,...



Measure $\Gamma(h \to \gamma\gamma) = \frac{[\Gamma(h \to \gamma\gamma) BR(h \to b\bar{b})]}{[BR(h \to b\bar{b})]}$

Note: BR(h→bb) measured to 1-2% in e+e-

Example: 2HDM
SM-like versus SM

SUSY: few % to 10%

H→bb study

Main background: photon - photon -> bb(g) and cc(g)

$$\frac{d\sigma^{Born}(J_z=0)}{dt} = \frac{12\pi\alpha^2 Q_q^4}{s^2}\frac{m_q^2 s^2(s-2m_q^2)}{t_1^2 u_1^2} \propto \boxed{\frac{m_q^2}{s}}$$

$$\frac{d\sigma^{Born}(J_z=\pm 2)}{dt} = \frac{12\pi\alpha^2 Q_q^4}{s^2}\frac{(t_1 u_1 - m_q^2 s)(u_1^2+t_2^2+2m_q^2)}{t_1^2 u_1^2}$$

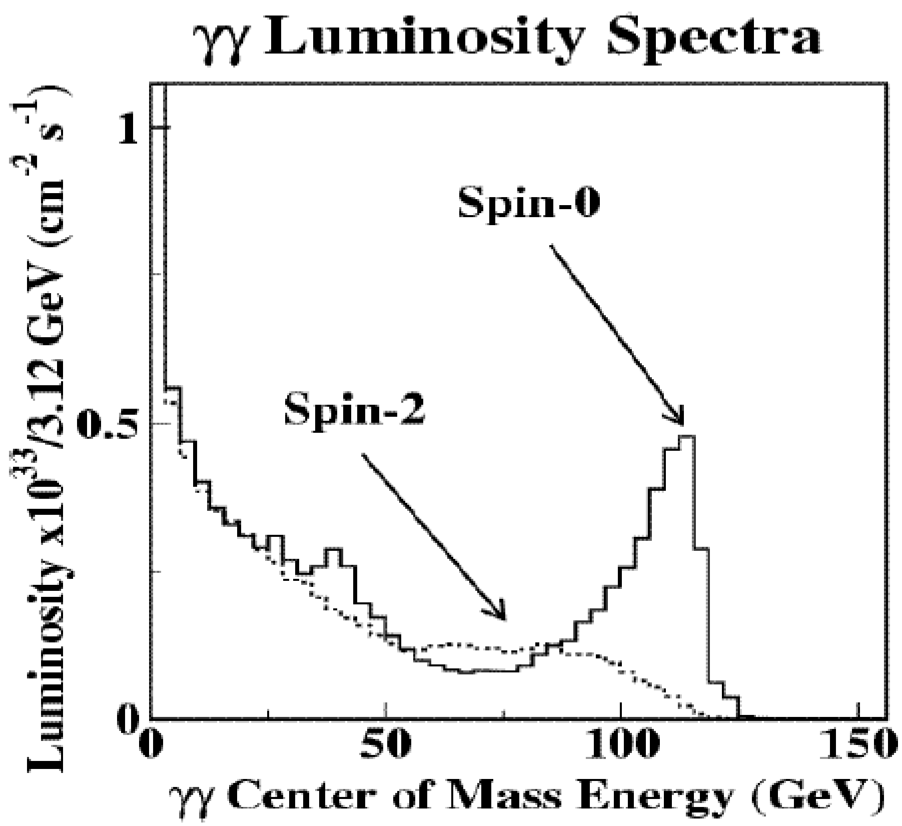
J_z suppression is only valid in LO

In general the background cross - sections have to be evaluated in NLO.

The NLO simulation of non - resonant background includes:

- exact one - loop QCD corrections (Jikia, Tkablazde)
- non - Sudakov form factor (Melles, Stirling, Khoze)

H→bb study



Two approaches:

1) Tune energy so that $\sqrt{s_{ee}} = m_h / 0.79$

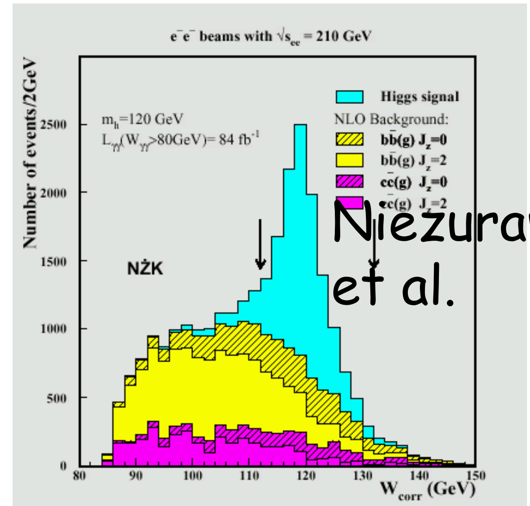
2) Go to maximum energy and search for Higgs in full spectrum

H→bb study

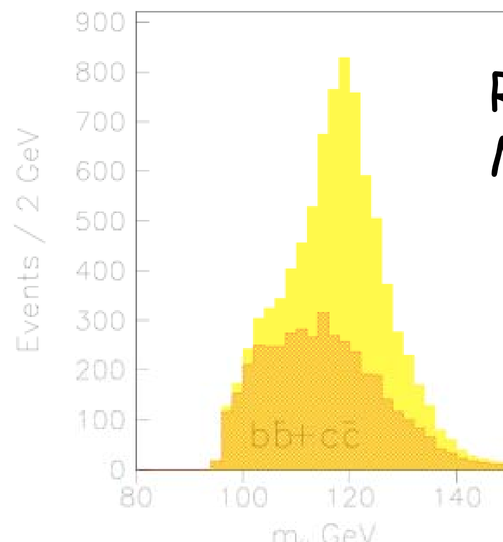
- Detailed analyses for Light SM Higgs
  - Realistic photon spectra: Tune collider energy such that maximum of the peak is at the Higgs mass
  - NLO QCD backgrounds (Jikia)
  - B-tagging via a neural network
  - Mass corrected for neutrinos
  - Add overlap QCD events (~1 per B.C.)
- Typical Cuts:
  - Durham jet algo. (y_{cut} = 0.02); θ_{min} = 450 mrad
  - |Pz|/Evis <0.15
  - 2 or 3 jets, each with |cos θ|<0.75

$$\frac{\Delta\sigma(\gamma\gamma\to h\to b\bar{b})}{\sigma(\gamma\gamma\to h\to b\bar{b})}=\frac{\Delta\left[\Gamma(h\to\gamma\gamma)\mathrm{Br}(h\to b\bar{b})\right]}{\left[\Gamma(h\to\gamma\gamma)\mathrm{Br}(h\to b\bar{b})\right]}=\frac{\sqrt{N_{obs}}}{N_{obs}-N_{bkgd}}.$$

Several analyses



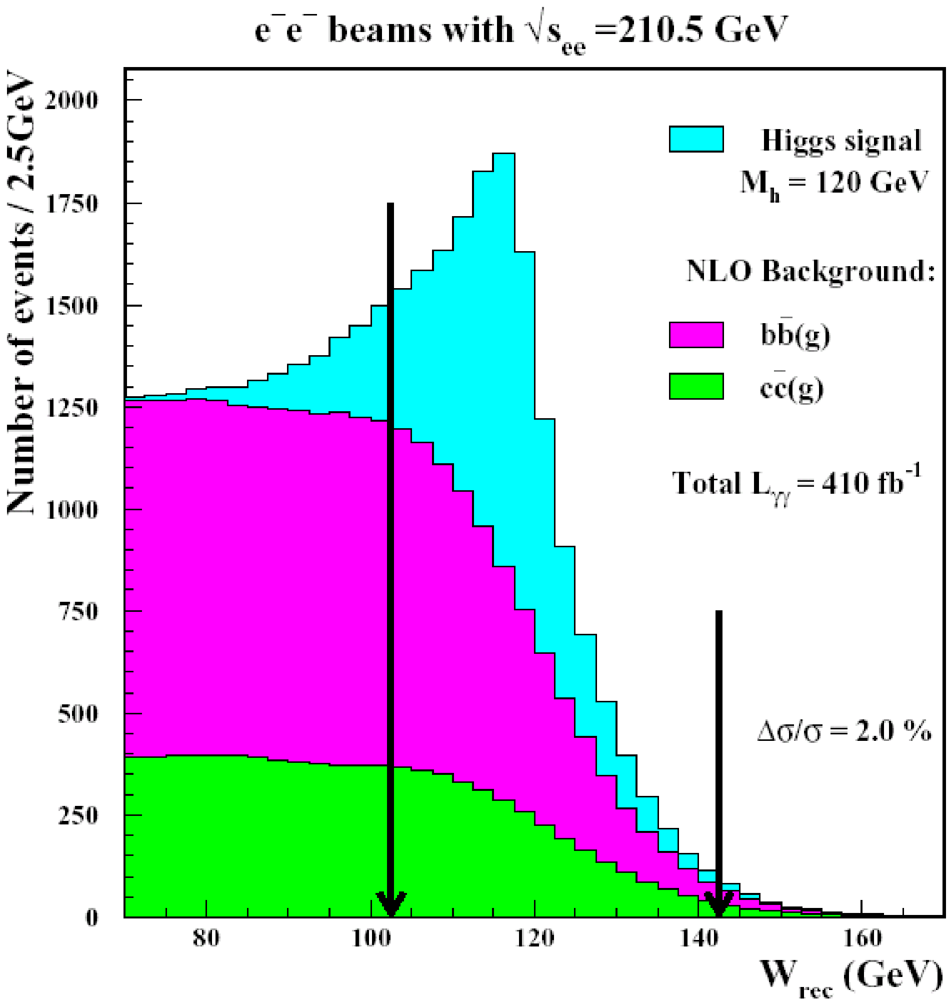
Niezurawski et al.

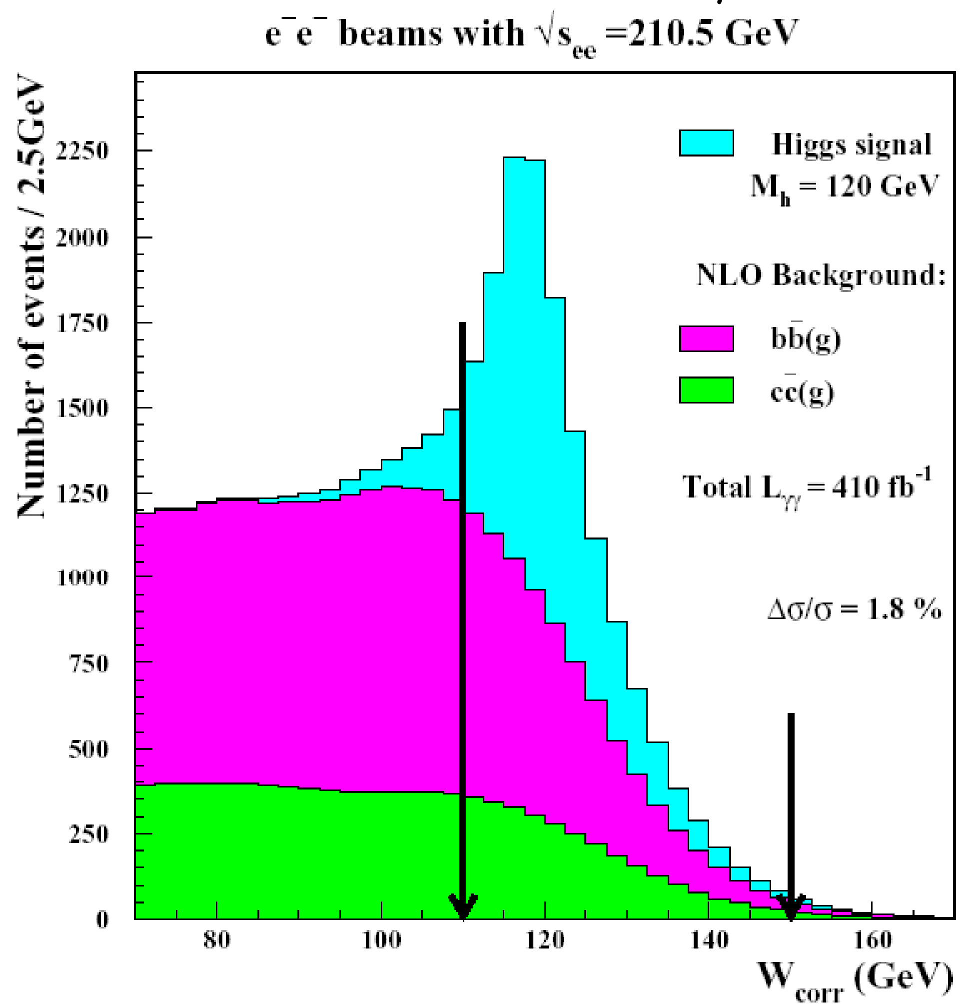


Rosca Moenig

H→bb study

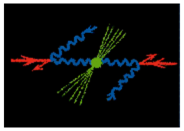
M.Krawczyk et al.



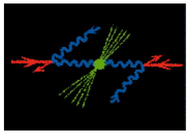


Improved mass calculation

$$W_{corr} \equiv \sqrt{W_{rec}^2 + 2P_T(E_{vis} + P_T)}$$

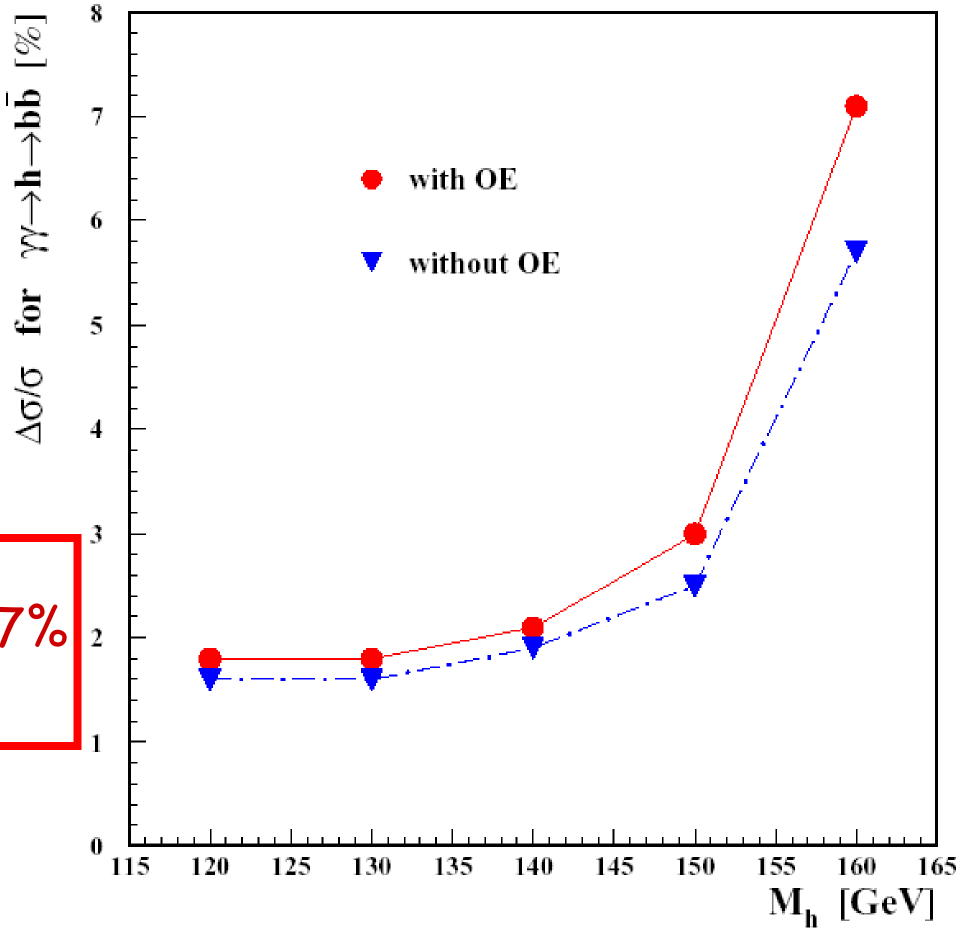


H→bb study



Measurement of $\Delta\sigma/\sigma$

$$\frac{\Delta[\Gamma(h\to\gamma\gamma)\mathrm{BR}(h\to b\bar{b})]}{[\Gamma(h\to\gamma\gamma)\mathrm{BR}(h\to b\bar{b})]} \approx 1.8\%\text{-}7\%$$



Br(H→bb) in e+e- known to better than 2%

arXiv:0705.1259 ⇒ 2-3%

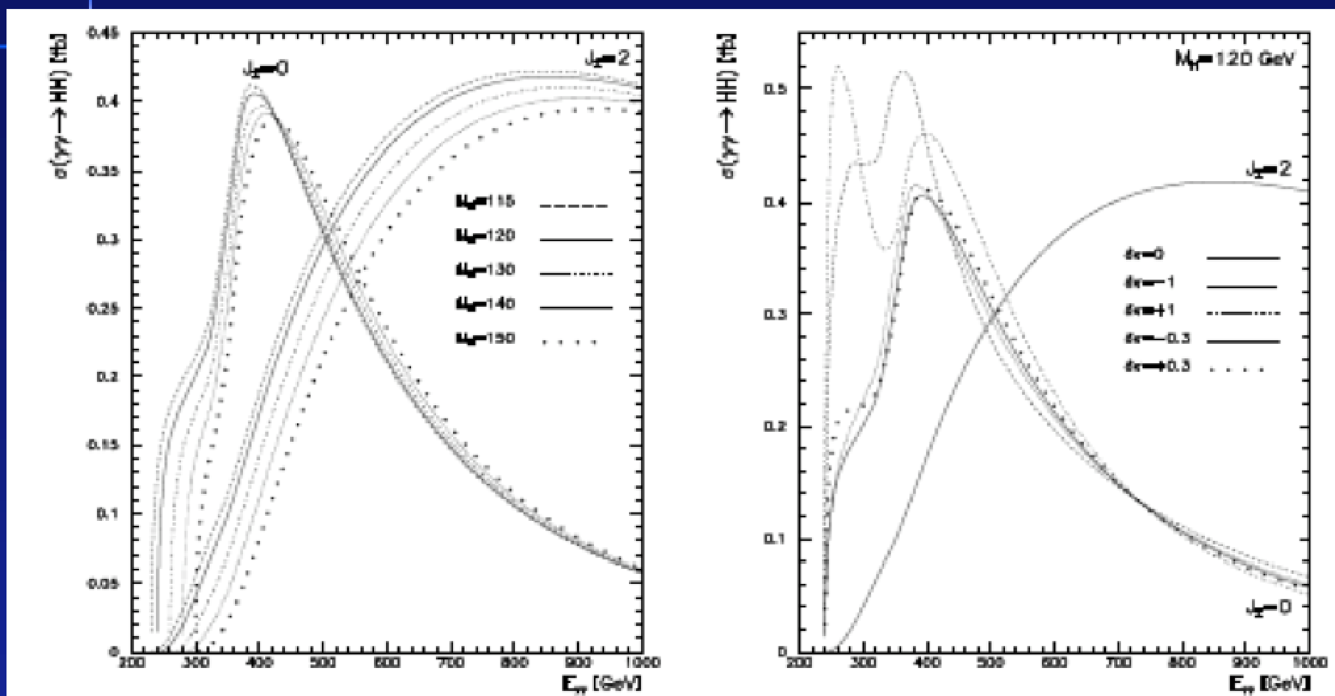
OE: overlap events
Low energy ~ 1 extra events
High energy ~ 2 extra events

Higgs Self Coupling

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

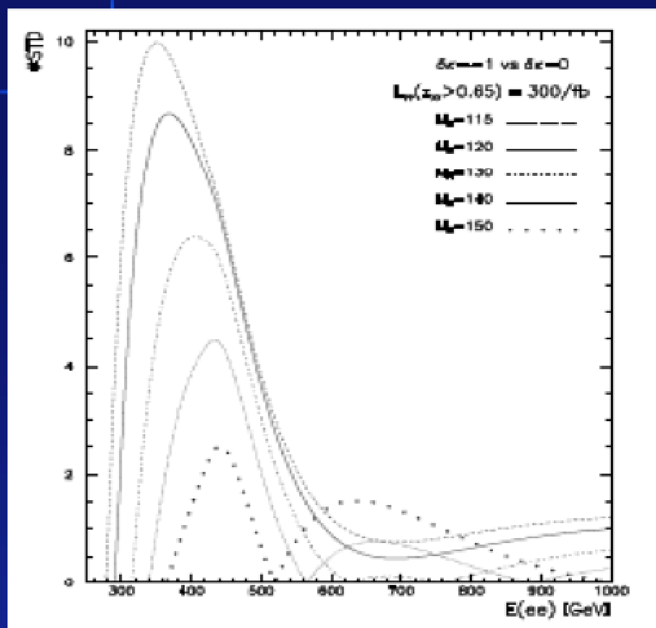
For Higgs mass = 120 GeV, anomalous contr. |δ|=0.1,0.3

Higgs Self Coupling

Effective hhh coupling vs SM using STD (standard deviations) – mass 120, 150GeV

PLC sensitive at lower energy than ee ILC

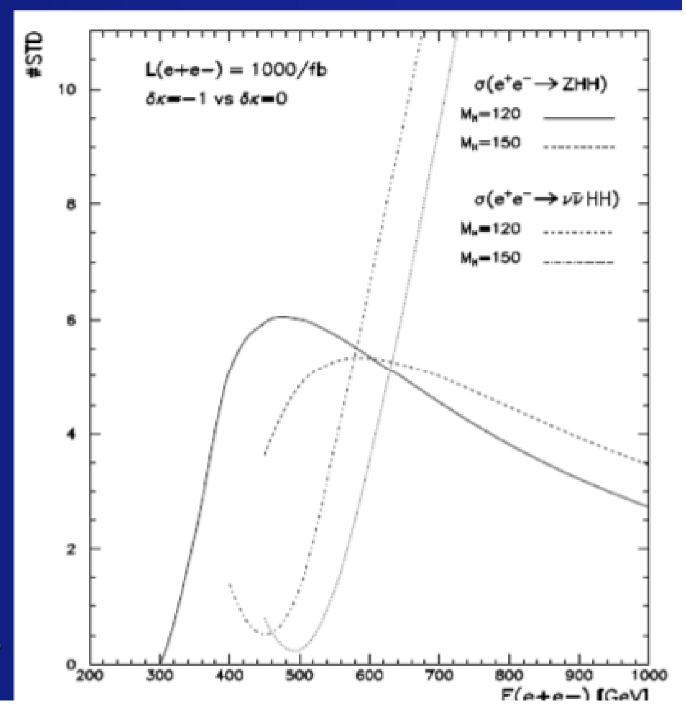
γ γ



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

$\delta = 0$ –> **SM** ; δ **=** -1 cancels the SM hhh contr.

e^+e^-

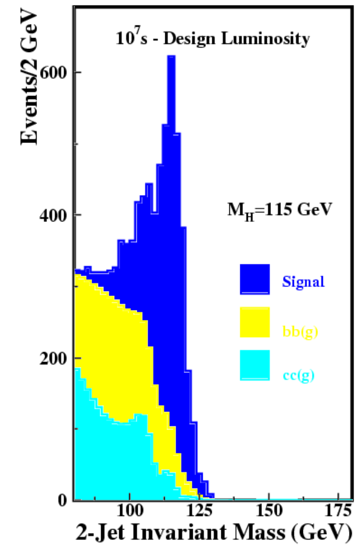


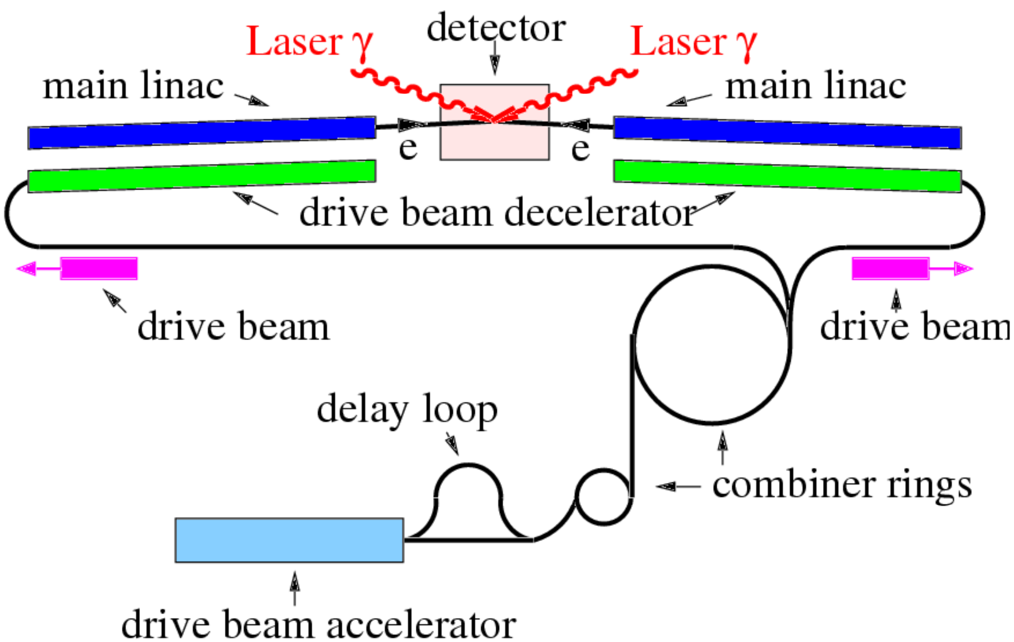
CLICHE

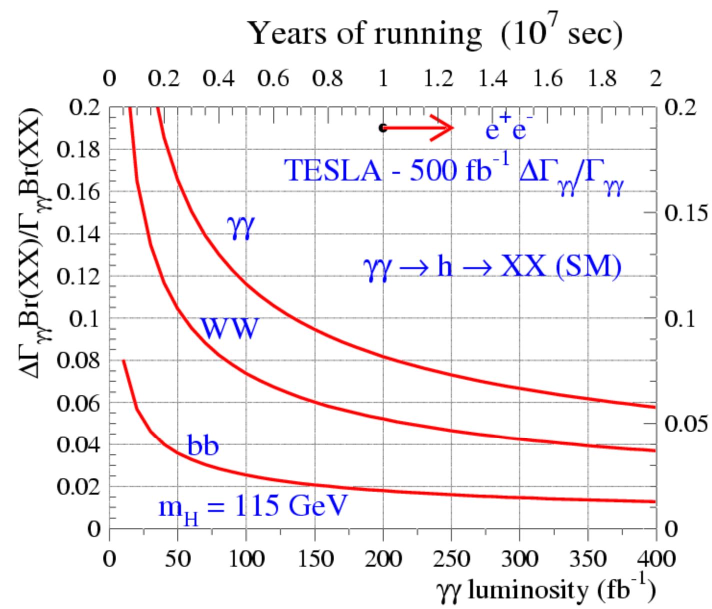
D. Asner, ADR, et al., hep-ex/0111056

CLICHÉ: CLIC Higgs Experiment

- Possible demonstration project for CLIC after CTF3 (ends 2009-2010)
- Uses only 2 CLIC modules (5%)
- Measure Higgs & more

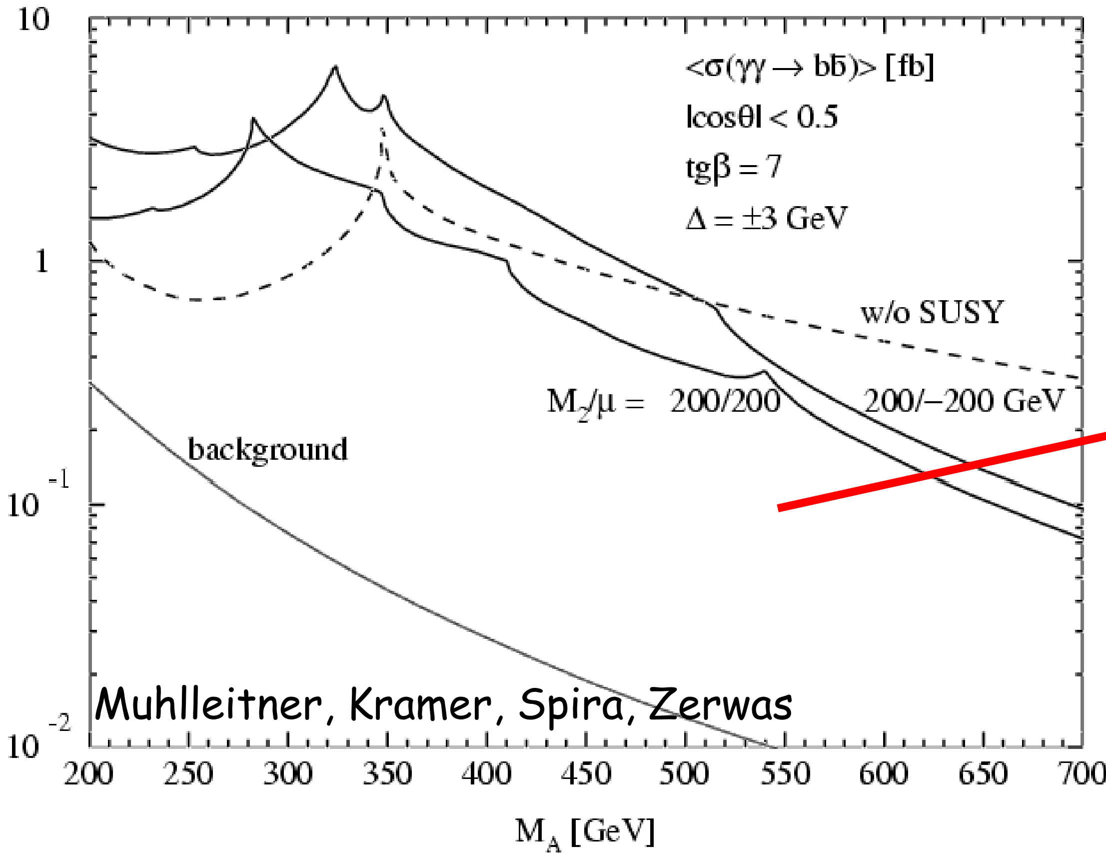


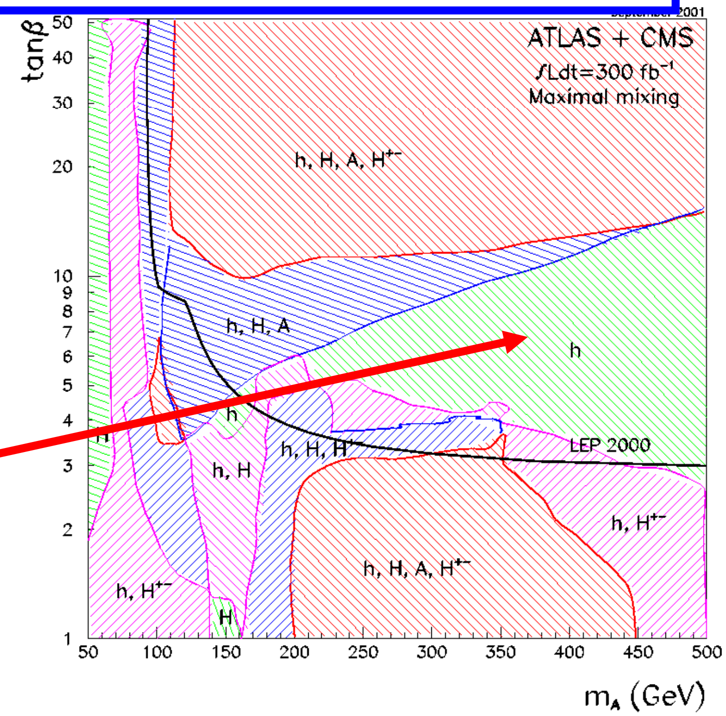




MSSM Higgs: H,A

Minimal Supersymmetric SM: 5 Higgses: h,H (CP even), A (CP odd) and $H^{\pm}$





Can a photon collider close the LHC wedge?

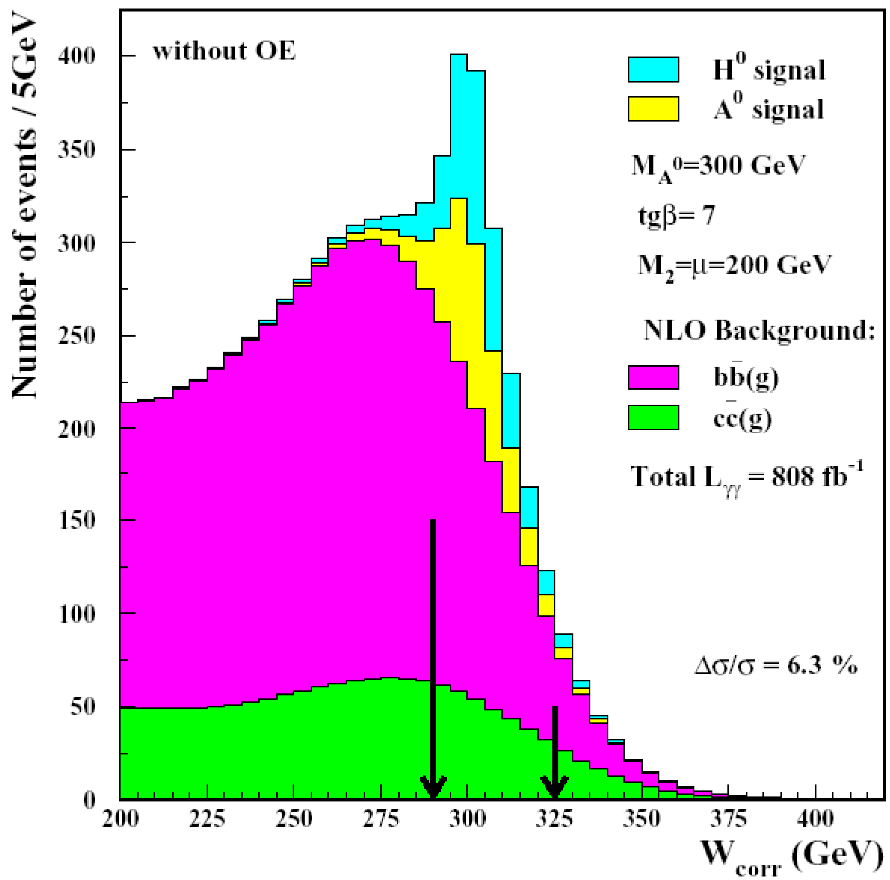
e+e- collider: H,A produced in pairs, hence M_A reach is $\sqrt{s_{ee}}/2$
γγ collider: s-channel production, hence M_A reach is $0.8 \cdot \sqrt{s_{ee}}$

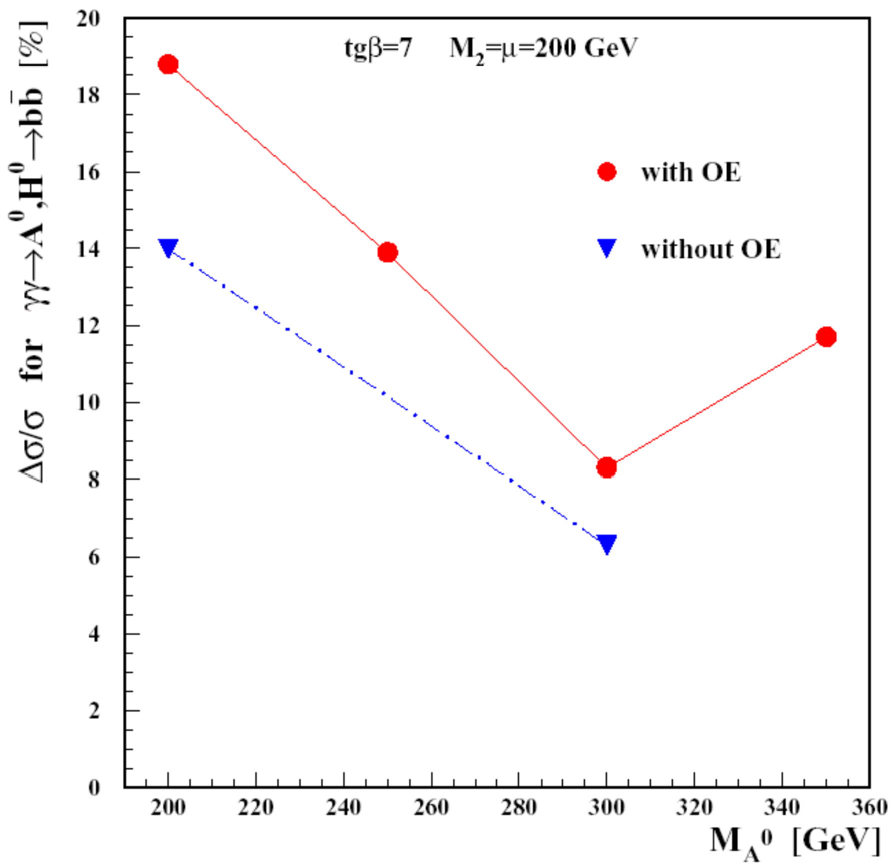
$H,A \to bb$ Study

M_A = 200,250,300,350 $\tan\beta$ =7

H,A degenerate

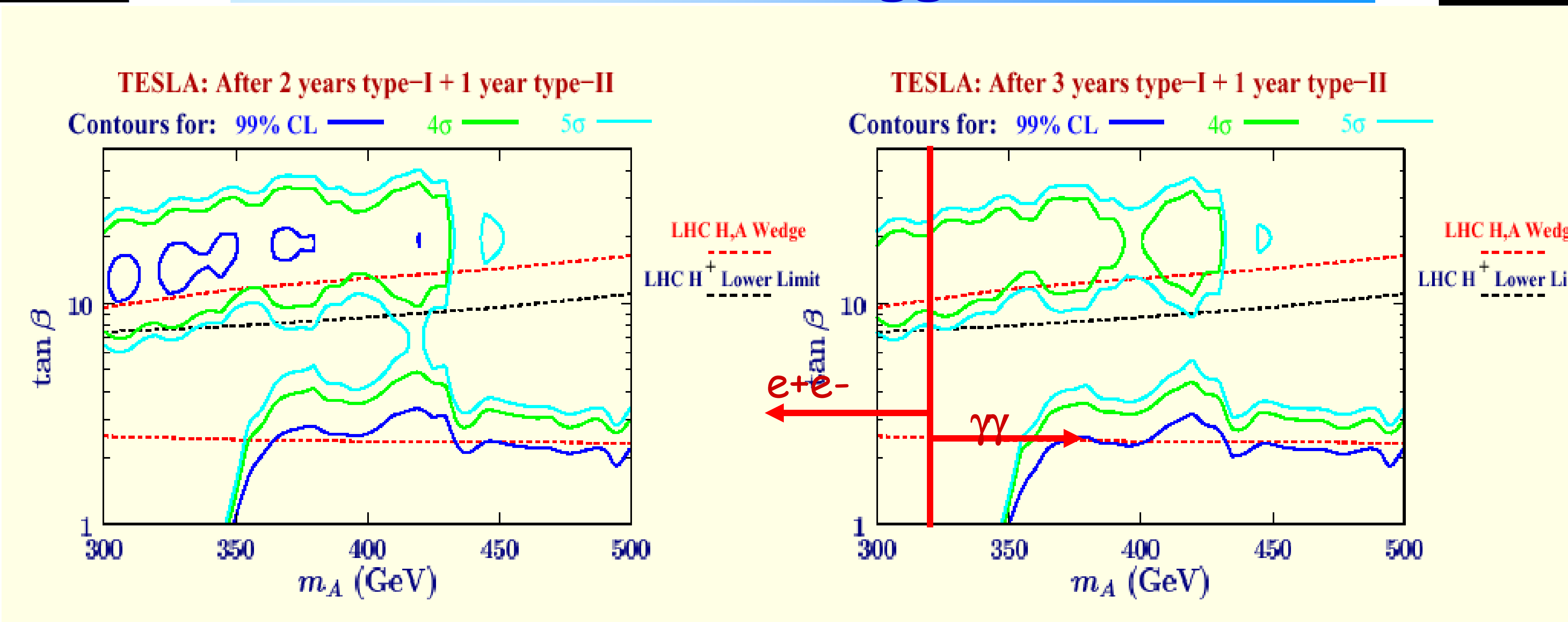
e^-e^- beams with $\sqrt{s_{ee}}$ =419 GeV





Measurement of $\Delta\sigma/\sigma$ to 10-20% (1 year running)

MSSM H/A Higgs Reach



US study D.Asner/J.Gunion (LCWS02)

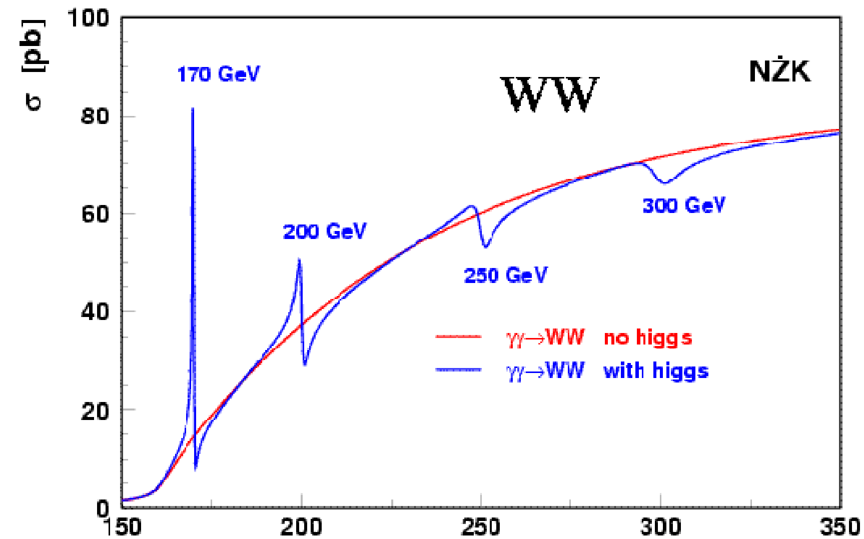
- Extends e+e- reach
- Need few years to close the LHC wedge

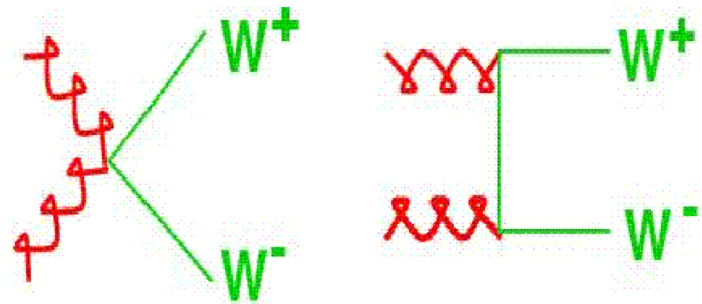
Study for a e+e- collider at 630 GeV

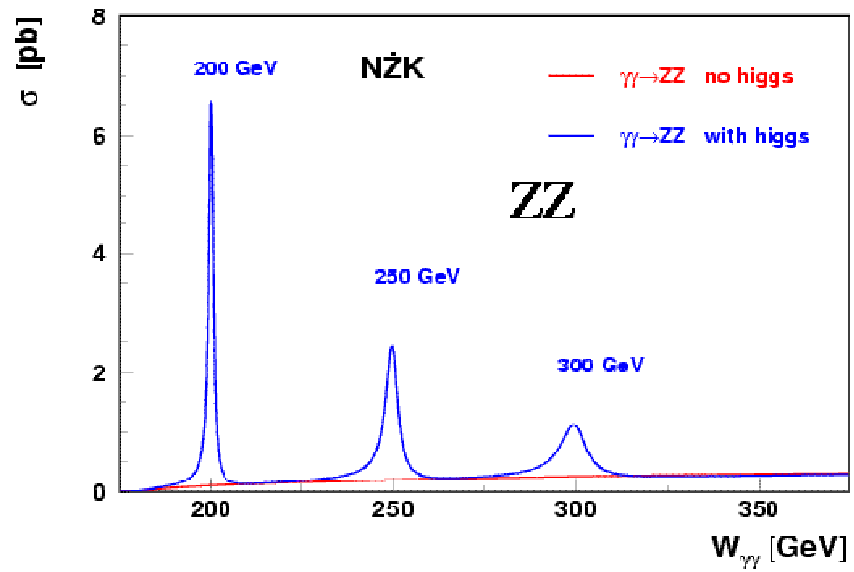
H→WW and ZZ study

Higgs Decaying into WW or ZZ

M.Krawczyk et al.







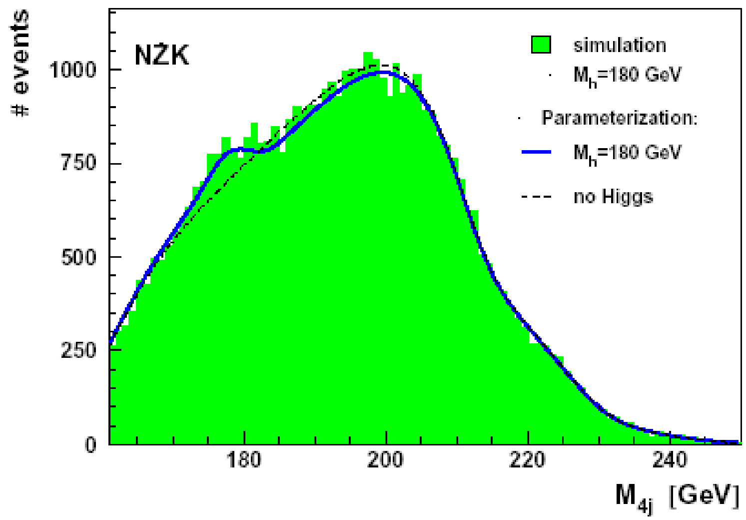
Large background from WW production:

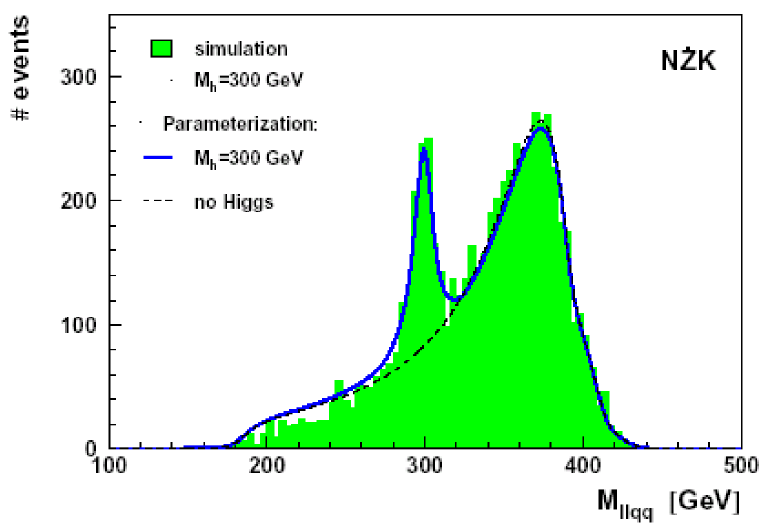
interference must be taken into account

<u>additional observable:</u>

phase $\phi_{\gamma\gamma}$ of $\gamma\gamma \to$ Higgs amplitude

H→WW and ZZ study





$\gamma\gamma \to WW$ for H=180 GeV

Similar analysis as for H→bb

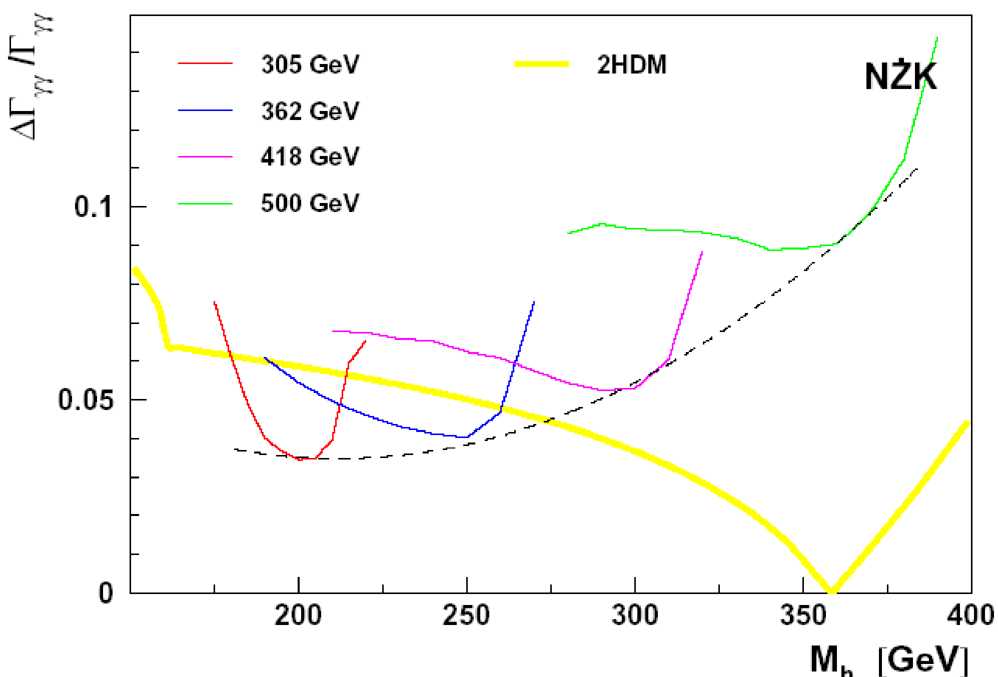
Select events with

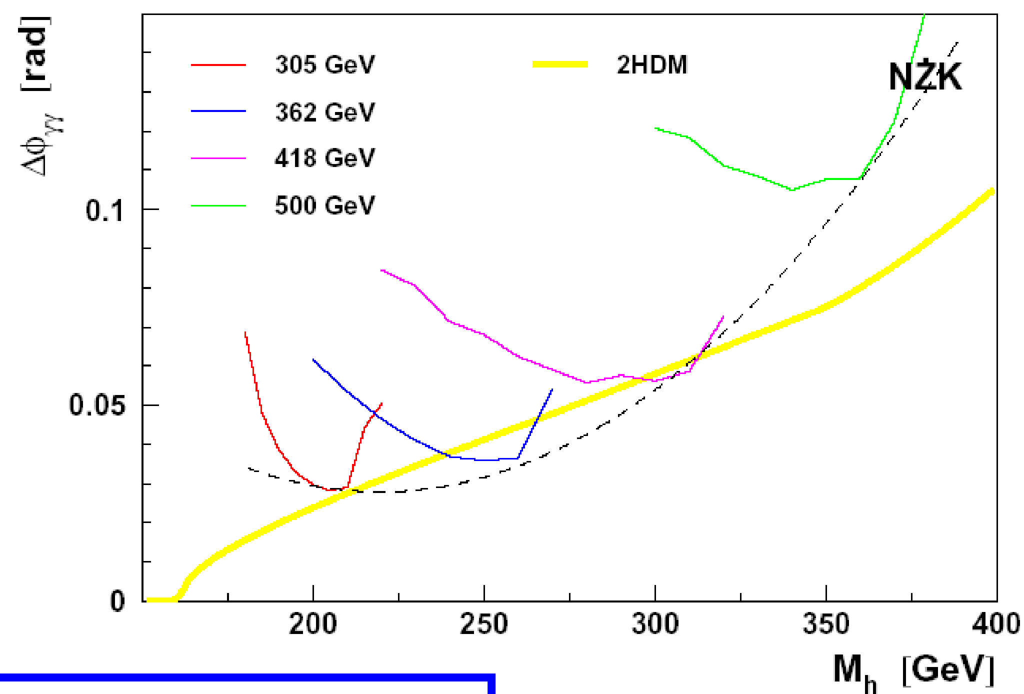
W+W- → 4 jets
Z Z → 2 leptons + 2 jets

$\gamma\gamma \to ZZ$ for H=300 GeV

H→WW and ZZ study

Statistical error on the Higgs width and phase from a combined ZZ and WW fit





$\Delta\Gamma\gamma\gamma/\Gamma\gamma\gamma$ = 3-10% M_H< 350 GeV

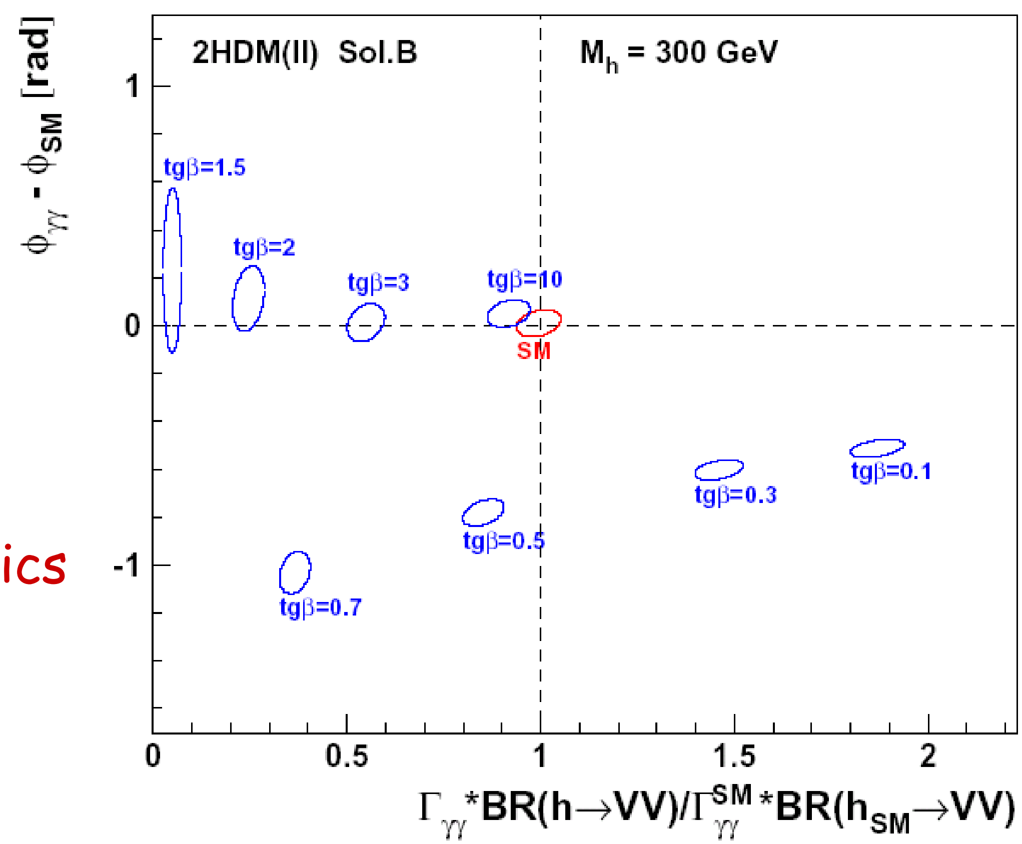
The yellow line shows the size of the deviations expected in the SM-like two higgs doublet model (2HDM=II) with an additional contribution due to the charged Higgs of mass 800 GeV.

Determination of Couplings in 2HDM

Deviations in two photon width and phase can appear if couplings are different from the SM ones
Eg. SM-like 2HDM/Couplings to EW gauge bosons are different
No CP violation in this model

	h	H	A
χ_u	-1	$-\frac{1}{\tan\beta}$	$-i\ \gamma_5\ \frac{1}{\tan\beta}$
χ_d	$+1$	$-\tan\beta$	$-i\ \gamma_5\ \tan\beta$
χ_V	$\cos(2\beta)$	$-\sin(2\beta)$	0

By measuring the phase and branching ratios to W's and Z's one can extract model characteristics



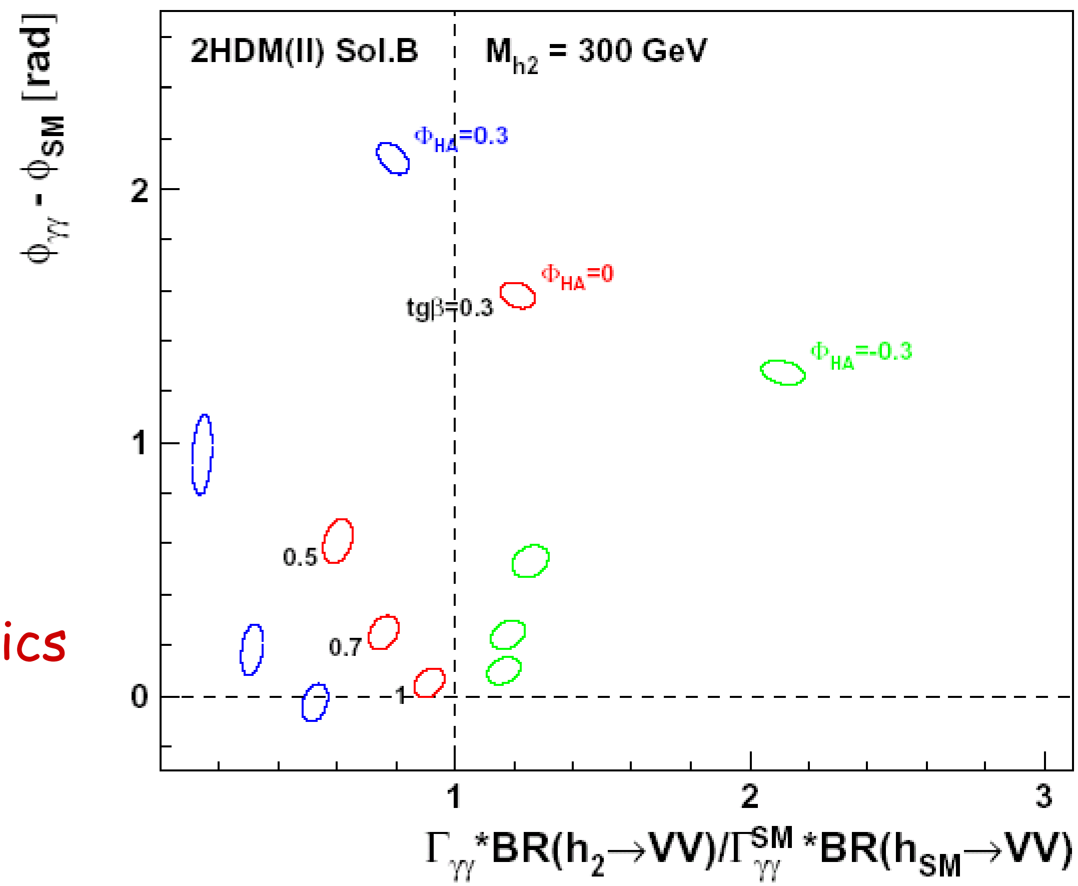
Determination of Couplings in 2HDM

Deviations in two photon width and phase can appear if couplings are different from the SM ones

Eg. SM-like 2HDM/Couplings to EW gauge bosons are different

Allow for CP violation!

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



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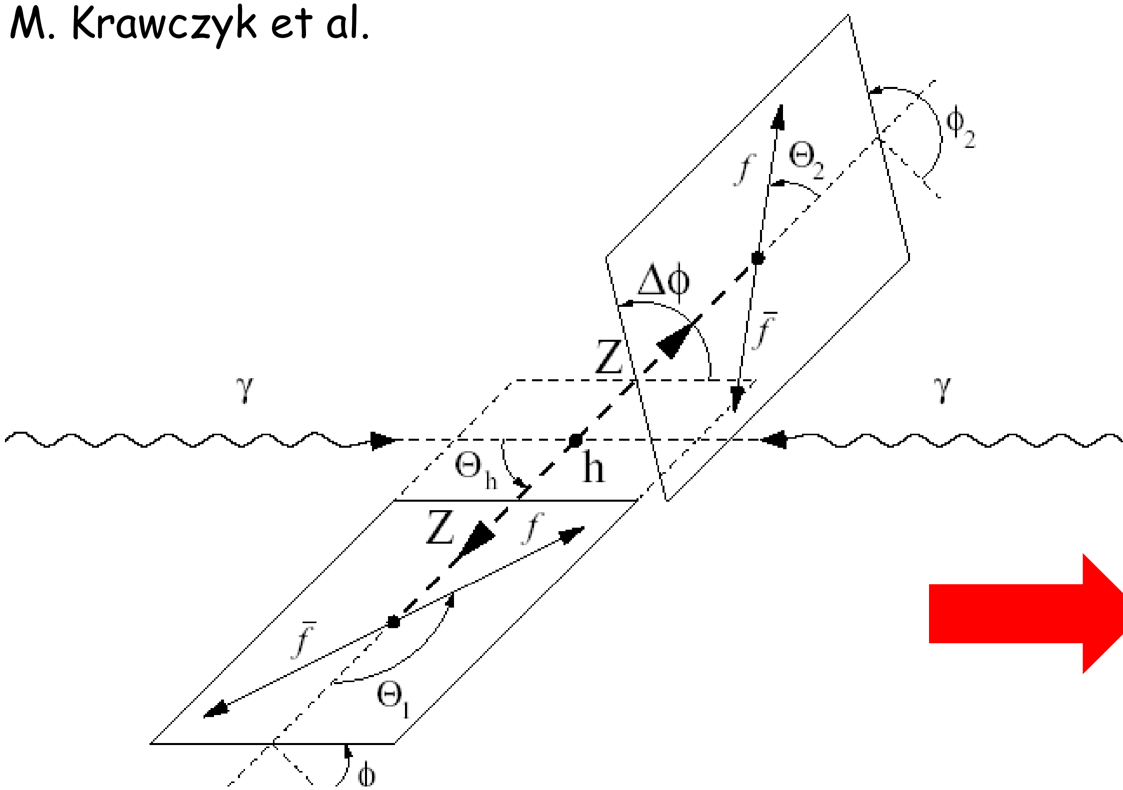
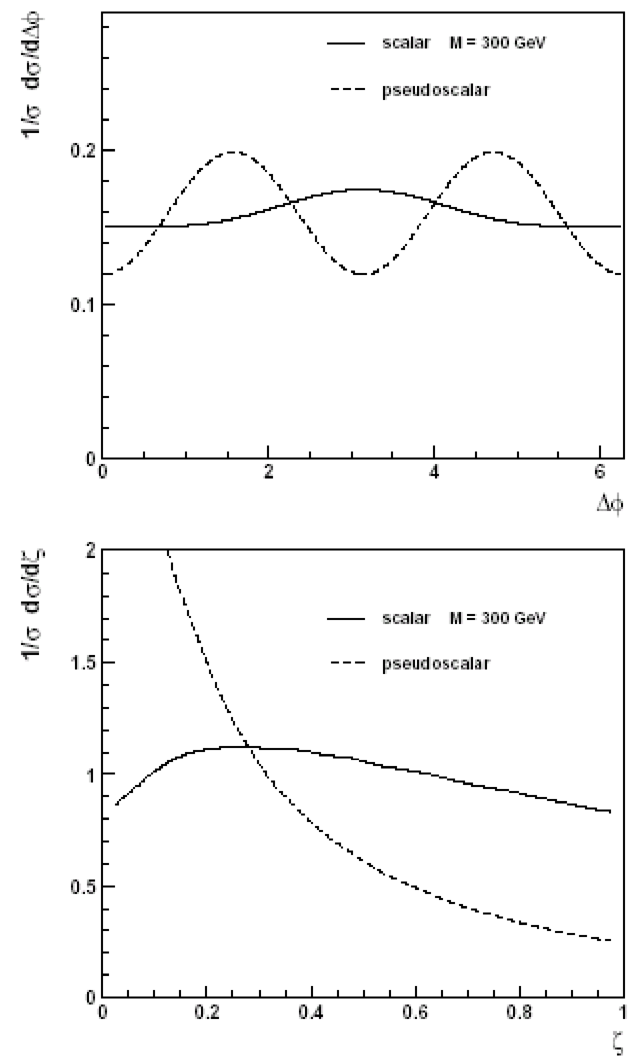
CP Analysis in ZZ,WW decays

M. Krawczyk et al.





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

ζ: Ratio of the angular distributions expected for a scalar and pseudoscalar

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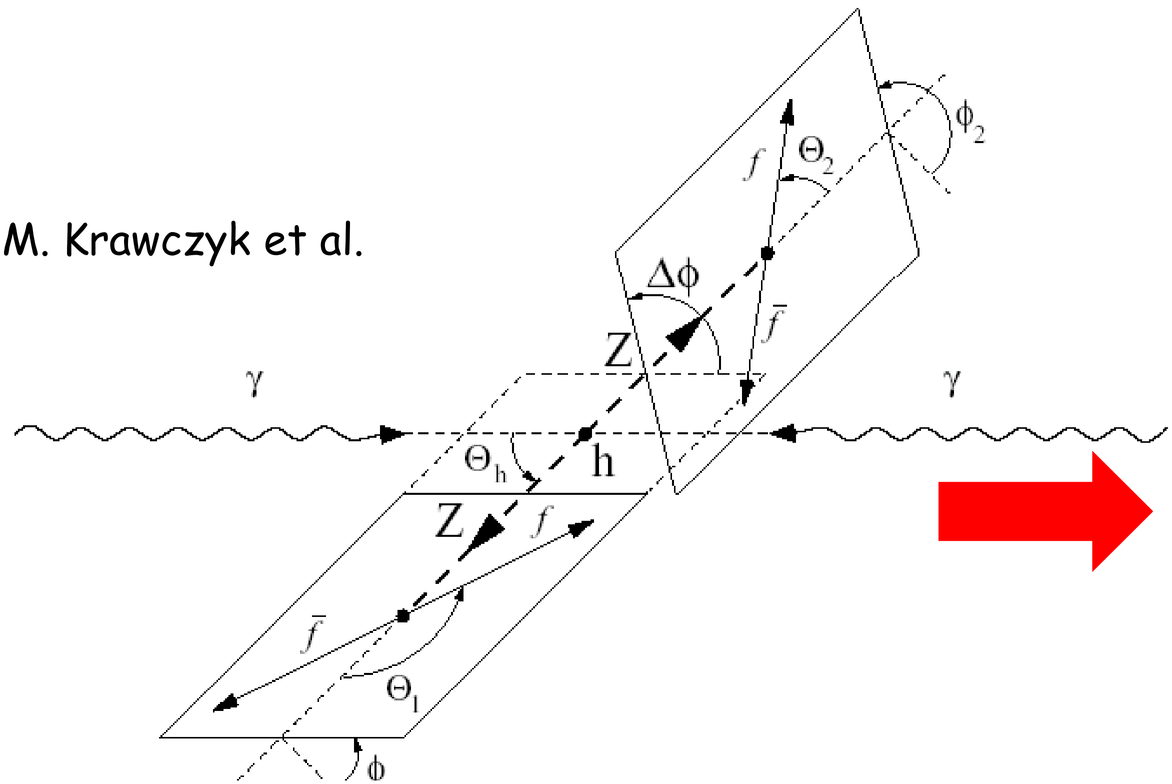
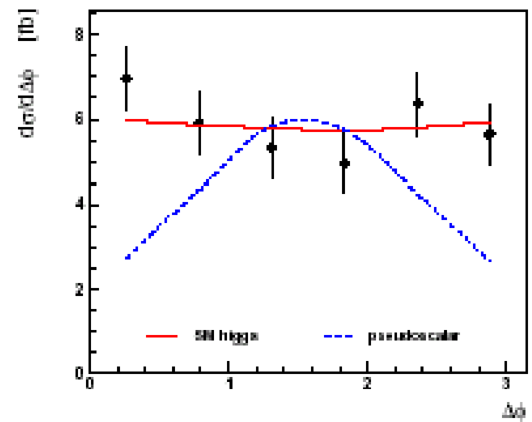


Angle between two decay planes

Realistic simulation

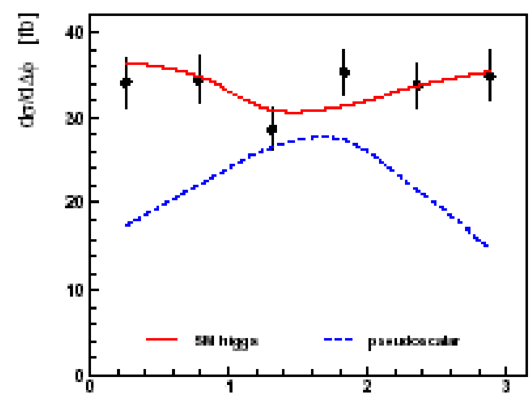
Extracted $\frac{d\sigma}{d\Delta\phi} \times BR(h \to ZZ)$

m_h = 300 GeV, $\sqrt{s_{ee}}$=418 GeV

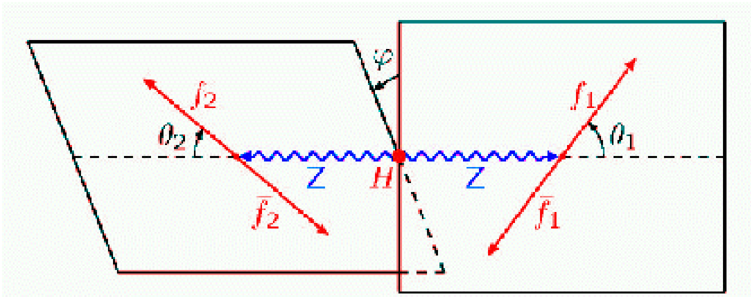


Extracted $\frac{d\sigma}{d\Delta\phi} \times BR(h \to WW)$

m_h = 200 GeV, $\sqrt{s_{ee}}$=305 GeV



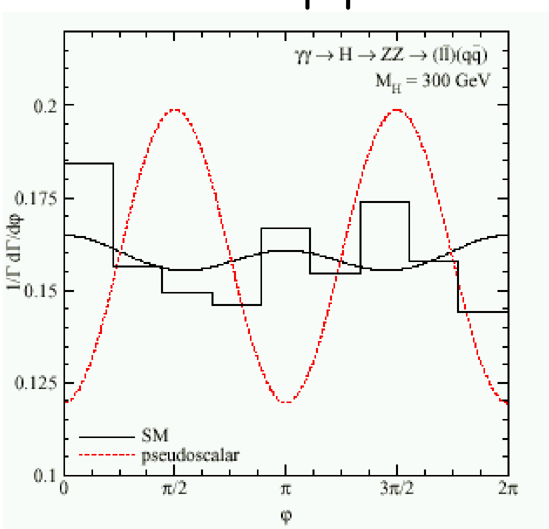
Angular distributions in $\gamma\gamma \to h \to ZZ \to lljj$ and $\gamma\gamma \to h \to WW \to 4j$



angle between two planes: $\Delta\phi = \phi_j - \phi_l$

⇒ Higgs spin and parity

D. Miller et al. hep-ph/0210077



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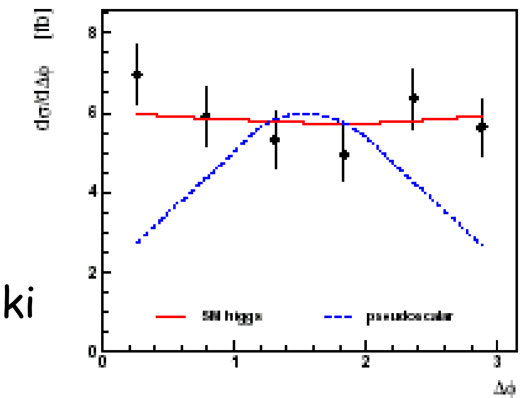
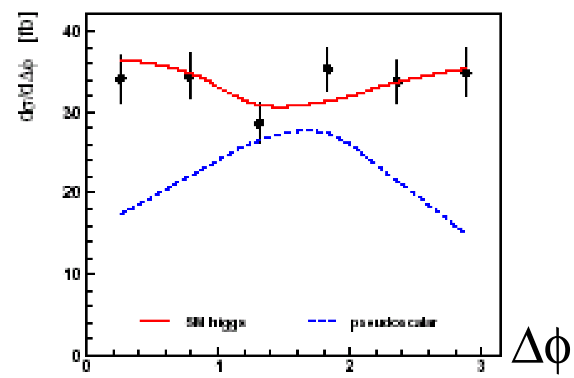


A. Zarnecki

Extracted $\frac{d\sigma}{d\Delta\phi} \times BR(h \to WW)$

m_h = 200 GeV, $\sqrt{s_{ee}}$=305 GeV



Detector effects are large, but sensitivity left

Generic model with CP violation

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

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

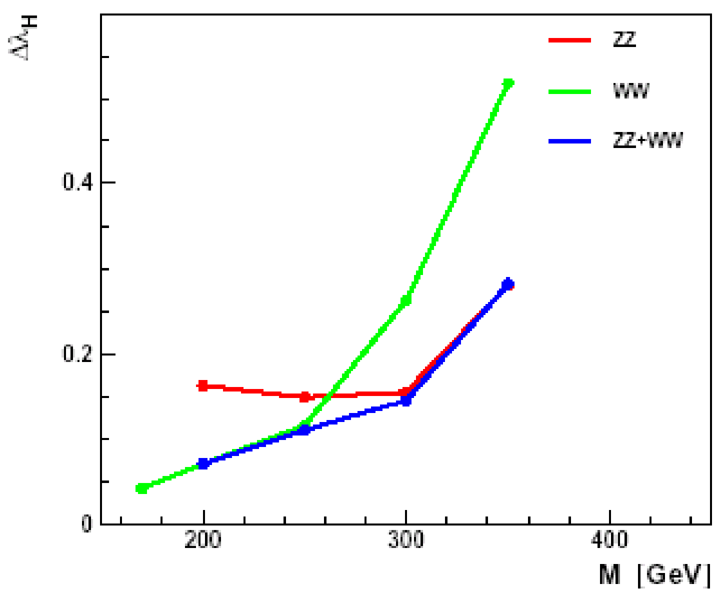
Standard Model (scalar) couplings are reproduced for $\lambda_H = 1$ and $\lambda_A = 0$.

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

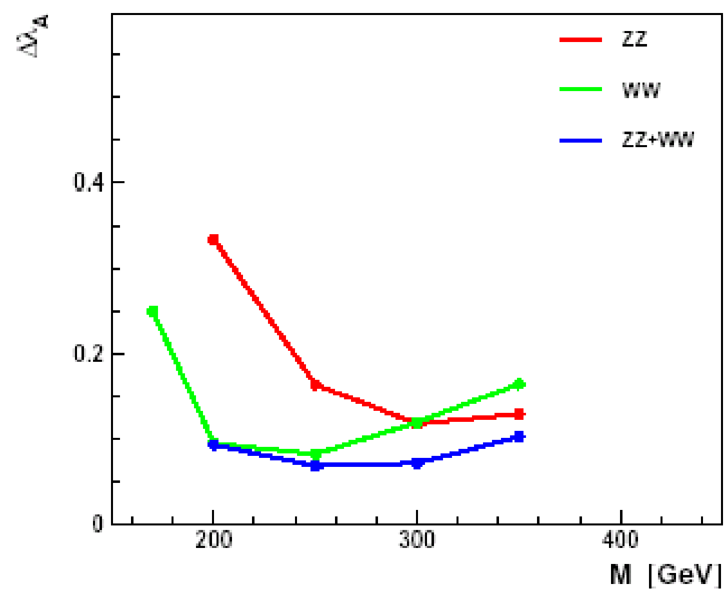
Combined measurement of angular correlations in the W^+W^- and ZZ-decay products

Measurement error for Higgs-boson couplings to vector bosons:

scalar



pseudoscalar

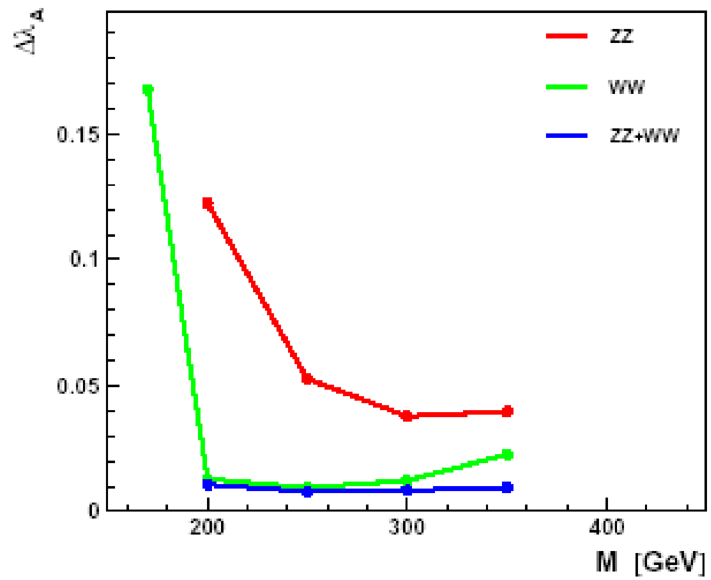


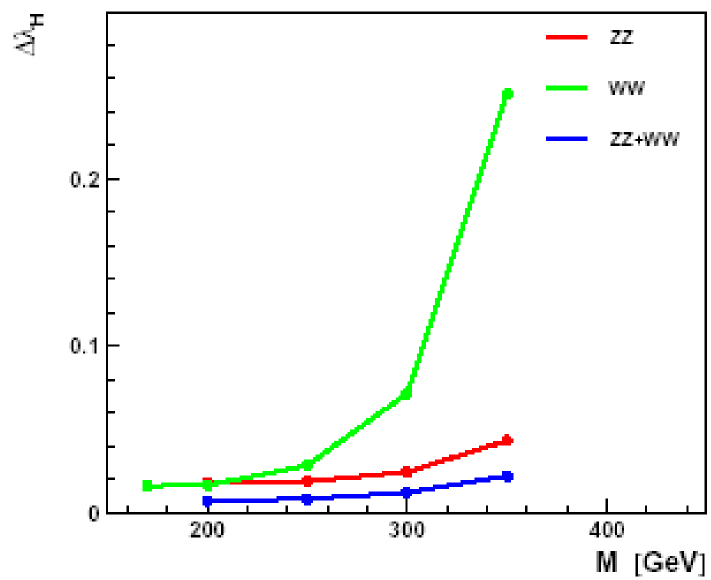
Precision on λ_A and λ_H

From $\Delta\phi$ and ζ measurements in ZZ and WW Higgs decays

Assume 'new physics' is only in the anomalous couplings:
$\Rightarrow$ no significant contributions of heavy particles

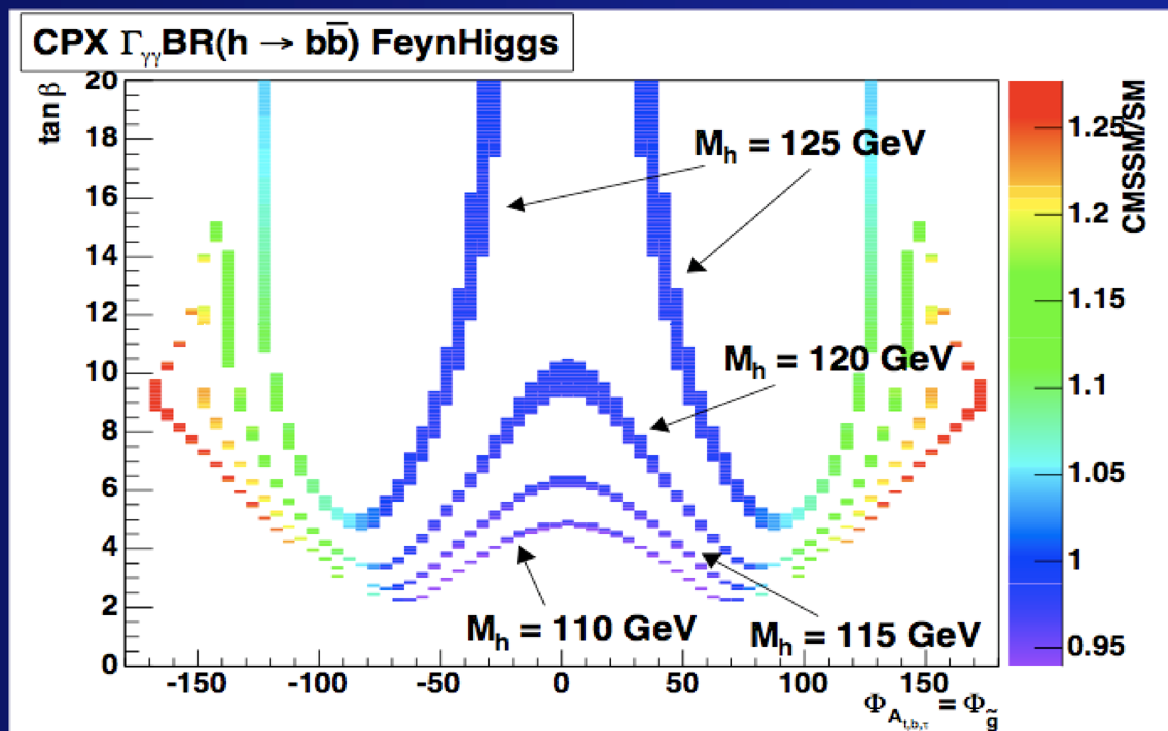
Use all information available (inv. mass, angular distr.)





CP violation

CPX scenario (max CP violation in CMSSM)
studied for LHC, ILC, PLC (CLIC ?)
by Heinemeyer, Velasco 2004



Linear polarized beams

If $\vec{\epsilon}_1$ and $\vec{\epsilon}_2$ are the photon polarization vectors (which are perpendicular to the beam), then

$\vec{\epsilon}_i$ are parallel $\longrightarrow$ produce CP-even only $\rightarrow$ H

$\vec{\epsilon}_i$ are perpendicular $\longrightarrow$ produce CP-odd only $\rightarrow$ A

Define an asymmetry

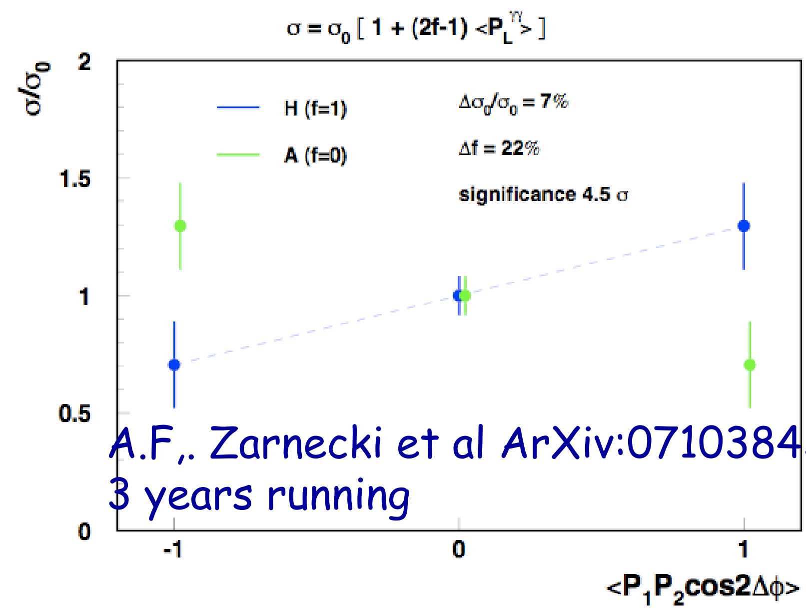
$$A \equiv \frac{N_{\parallel} - N_{\perp}}{N_{\parallel} + N_{\perp}}$$

After taking backgrounds and realistic polarizat

$$\frac{\delta CP}{CP} = \frac{\delta A}{A} = 0.11$$

after one year.

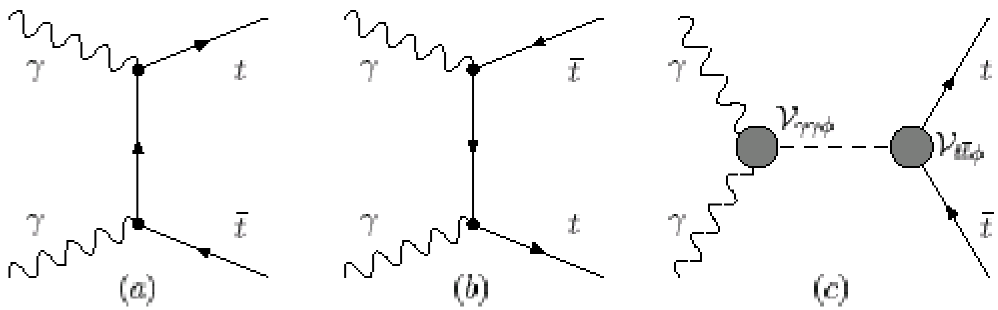
The CP-even nature of the Higgs boson could b
level.



A.F,. Zarnecki et al ArXiv:0710384
3 years running

Linear polarization to produced either H or A (or mixture)

CP studies via $\gamma\gamma \rightarrow \phi \rightarrow tt$



$$\mathcal{A}_1 = \frac{\sigma(+,+) - \sigma(-,-)}{\sigma(+,+) + \sigma(-,-)}$$
$$\mathcal{A}_2 = \frac{\sigma(+,-) - \sigma(-,+)}{\sigma(+,-) + \sigma(-,+)}$$
$$\mathcal{A}_3 = \frac{\sigma(+,+) - \sigma(-,+)}{\sigma(+,+) + \sigma(-,+)}$$
$$\mathcal{A}_4 = \frac{\sigma(+,-) - \sigma(-,-)}{\sigma(+,-) + \sigma(-,-)}$$
$$\mathcal{A}_5 = \frac{\sigma(+,+) - \sigma(+,-)}{\sigma(+,+) + \sigma(+,-)}$$
$$\mathcal{A}_6 = \frac{\sigma(-,+) - \sigma(-,-)}{\sigma(-,+) + \sigma(-,-)}$$

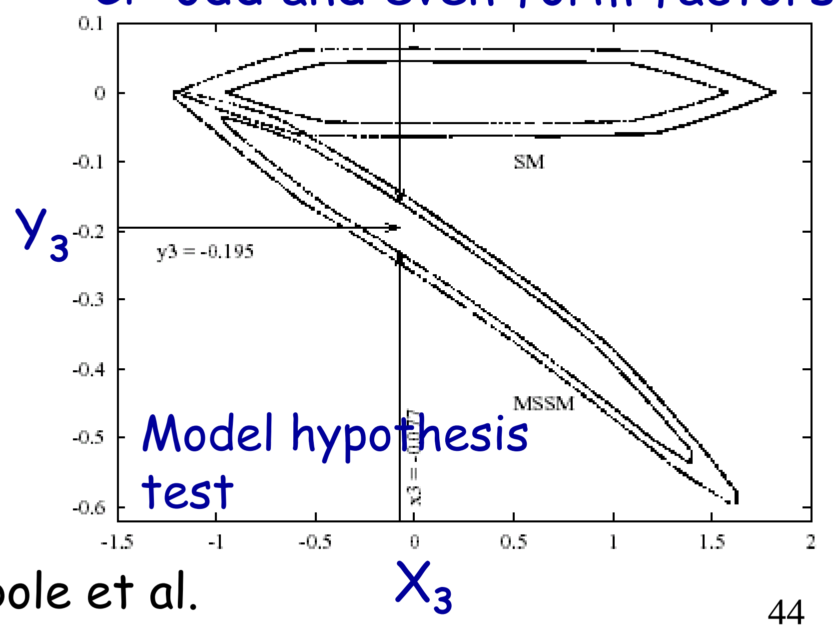
Charge
Helicity

Construct combined asymmetries from initial photon polarization and decay lepton charge e.g. $\gamma\gamma \rightarrow tt \rightarrow Wbt \rightarrow l^{+}\nu bt$

$$|\mathcal{A}(\{x_i, y_i\}) - \mathcal{A}_{SM}| \leq \delta\mathcal{A}_{SM} = \frac{f}{\sqrt{\sigma_{SM} L}}\sqrt{1 + \mathcal{A}_{SM}^2}$$

$$m_\phi = 500GeV, \Gamma_\phi 1.9GeV,$$
$$S_t = 0.33, P_t = 0.15,$$
$$S_\gamma = -1.3 - 1.2i, P_\gamma = -0.51 + 1.1i.$$

CP-odd and even form factors



R. Godbole et al.

$\gamma\gamma \to H \to \gamma\gamma$ study

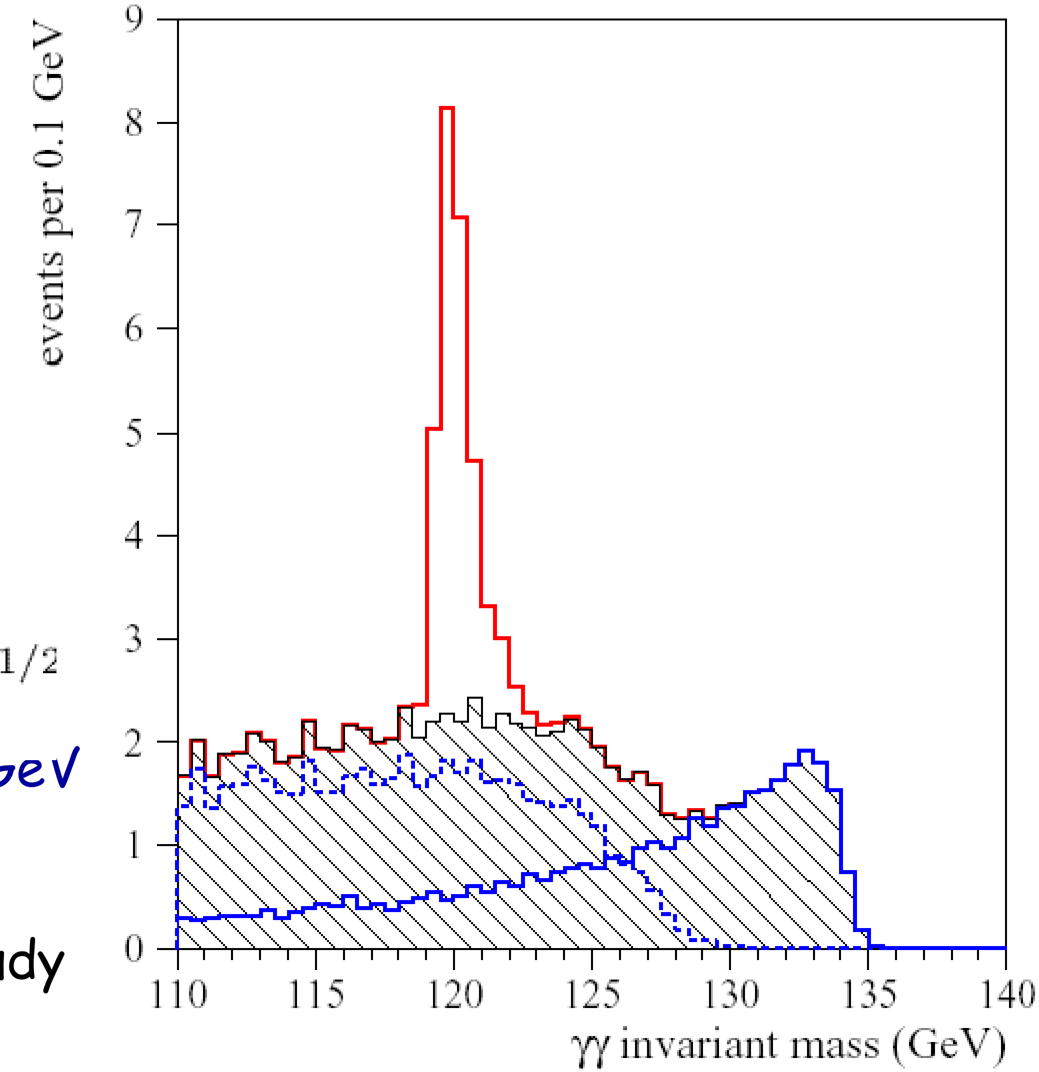
M. Schmidt

This channel is double sensitive to $\Gamma_{\gamma\gamma}$

Event rate is small !!
Needs excellent electromagnetic calorimeter to be observable,
Here:

$$\sigma_E/E = \left((0.015/\sqrt{E})^2 + (0.0045)^2\right)^{1/2}$$

Mass resolution on the peak ~0.4 GeV
Can get Δm_H ~ 100 MeV
$\Delta\sigma/\sigma$ ~ 24%
Other modes, e.g. $H \to Z\gamma$ under study

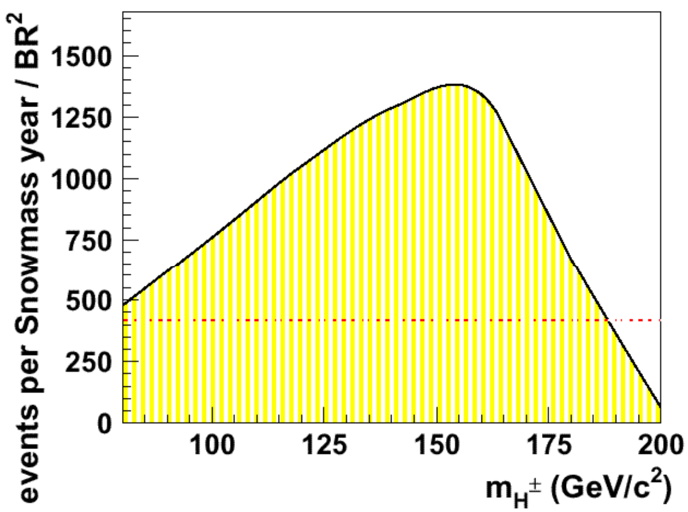


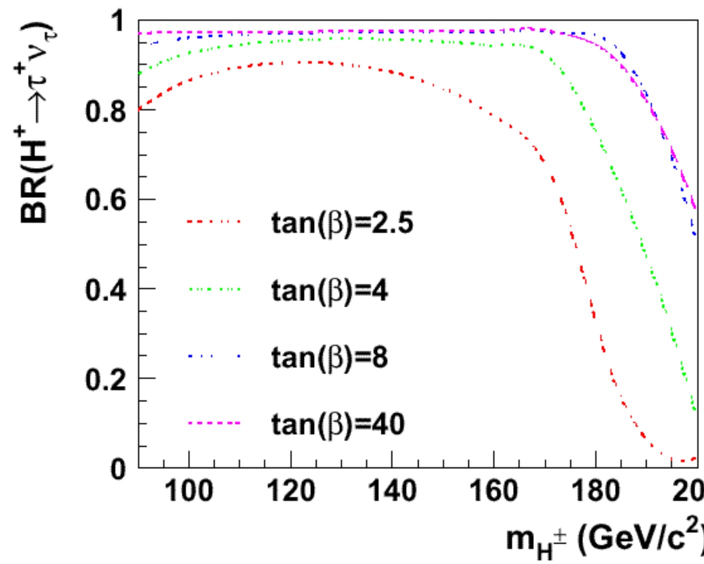
Charged Higgs

V. Martin

Cross section 20 times larger in $\gamma\gamma$ compared to e+e-

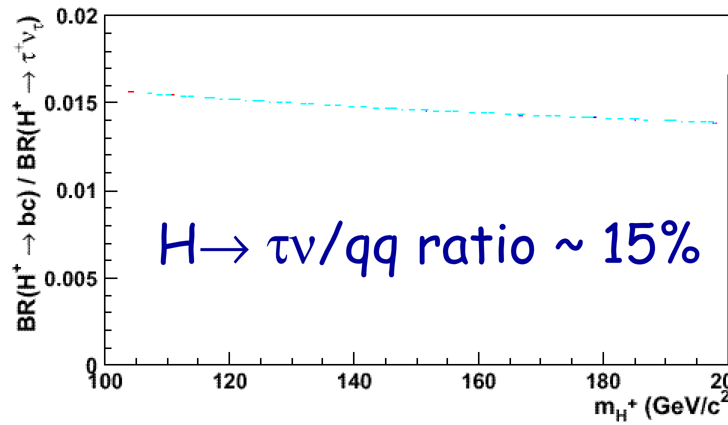
$$\gamma\gamma \to H^+H^- \to \tau^+\nu_\tau \tau^-\bar{\nu}_\tau$$





Clean signal (S/B ~ 3) but cannot be used to determine mass

Try $\tau\nu qq$ channel



H→ $\tau\nu$/qq ratio ~ 15%

Next-to-MSSM Study

Going beyond the simplest model e.g. NMSSM:
⇒7 Higgs particles: 3 CP even (h1,h2,h3), 2CP odd (a1,a2) and 2 charged

Point Number	1	2	3	4	5	6
Bare Parameters						
λ	0.2872	0.2124	0.3373	0.3340	0.4744	0.5212
κ	0.5332	0.5647	0.5204	0.0574	0.0844	0.0010
$\tan\beta$	2.5	3.5	5.5	2.5	2.5	2.5
$\mu_{\rm eff}$ (GeV)	200	200	200	200	200	200
A_λ (GeV)	100	0	50	500	500	500
A_κ (GeV)	0	0	0	0	0	0
CP-even Higgs Boson Masses and Couplings						
m_{h_1} (GeV)	115	119	123	76	85	51
Relative gg Production Rate	0.97	0.99	0.99	0.00	0.01	0.08
$BR(h_1 \to b\bar{b})$	0.02	0.01	0.01	0.91	0.91	0.00
$BR(h_1 \to \tau^+\tau^-)$	0.00	0.00	0.00	0.08	0.08	0.00
$BR(h_1 \to a_1 a_1)$	0.98	0.99	0.98	0.00	0.00	1.00
m_{h_2} (GeV)	516	626	594	118	124	130
Relative gg Production Rate	0.18	0.09	0.01	0.98	0.99	0.90
$BR(h_2 \to b\bar{b})$	0.01	0.04	0.04	0.02	0.01	0.00
$BR(h_2 \to \tau^+\tau^-)$	0.00	0.01	0.00	0.00	0.00	0.00
$BR(h_2 \to a_1 a_1)$	0.04	0.02	0.83	0.97	0.98	0.96
m_{h_3} (GeV)	745	1064	653	553	554	535
CP-odd Higgs Boson Masses and Couplings						
m_{a_1} (GeV)	56	7	35	41	59	7
Relative gg Production Rate	0.01	0.03	0.05	0.01	0.01	0.05
$BR(a_1 \to b\bar{b})$	0.92	0.00	0.93	0.92	0.92	0.00
$BR(a_1 \to \tau^+\tau^-)$	0.08	0.94	0.07	0.07	0.08	0.90
m_{a_2} (GeV)	528	639	643	560	563	547
Charged Higgs Mass (GeV)	528	640	643	561	559	539
Most Visible Process No.	2 (h_1)	2 (h_1)	8 (h_1)	2 (h_2)	8 (h_2)	8 (h_2)
Significance at 300 fb^{-1}	0.48	0.26	0.55	0.62	0.53	0.16

1) $gg \to h/a \to \gamma\gamma$;
2) associated Wh/a or $t\bar{t}h/a$ production with $\gamma\gamma\ell^\pm$ in the final state;
3) associated $t\bar{t}h/a$ production with $h/a \to b\bar{b}$;
4) associated $b\bar{b}h/a$ production with $h/a \to \tau^+\tau^-$;
5) $gg \to h \to ZZ^{(*)} \to 4$ leptons;
6) $gg \to h \to WW^{(*)} \to \ell^+\ell^-\nu\bar{\nu}$;
7) $WW \to h \to \tau^+\tau^-$;
8) $WW \to h \to WW^{(*)}$.

Some of these Higgses cannot be seen at the LHC, if decay $h \to a_1 a_1 \to bbbb$ large

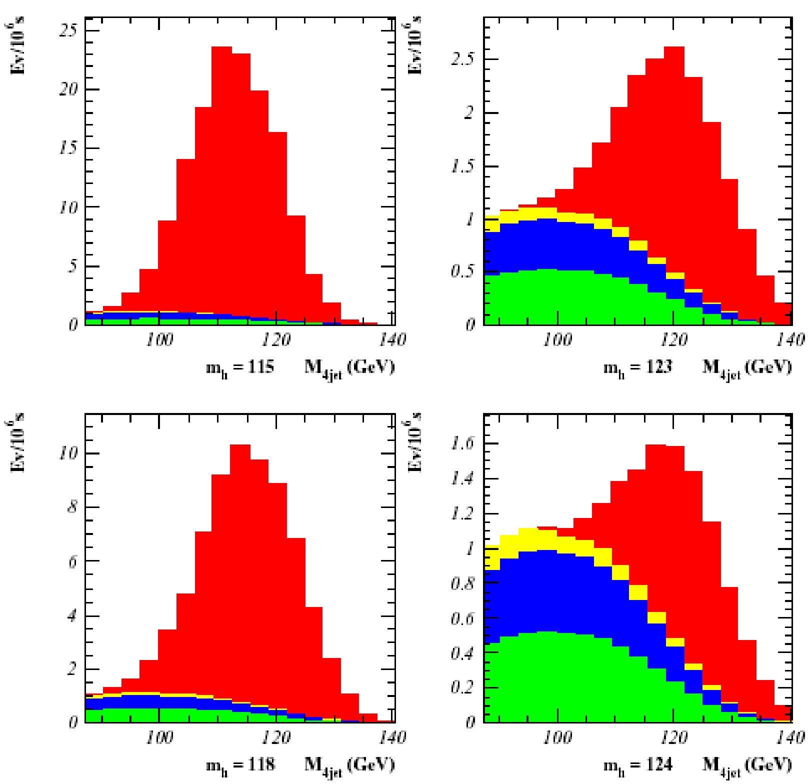
Low significance at the highest lumi

NMSSM at a PC

Scenario	m_h (GeV)	m_a (GeV)	$\sigma(\gamma\gamma \to h)$ (fb)	Acceptance	No. events / $10^6 s$
(1)	115	56	112	0.26	139
(3)	123	35	9.1	0.33	14.7
(4)	118	41	46	0.28	63
(5)	124	59	6.0	0.24	7.1

Asner et al.

SIGNAL on top of BACKGROUND - 4 SCENARIOS



Signals and background for
Four of the difficult LHC scenarios

Study $h \to a_1 a_1 \to bbbb$

Clear signals confirming/discovering
these low mass Higgses

Note e+e- $\to$Zh should see these
without problems

Higgs Wrap-up

- Mass
  - ~ 100 MeV/ 1 year running — ~e^+e^-
- Partial width $\Gamma(\gamma\gamma)$
  - 2-7% in bb channel (needs $H\rightarrow$ bb from e+e-) — 15% in e+e-
  - 3-10% in WW,ZZ channel (needs BR from e+e-) — ~e+e-
- Determination of the phase of the $\gamma\gamma \rightarrow$ Higgs amplitude — Unique?
  - 3-10% in WW,ZZ channel
- CP analysis: many posibilities — More handles than in e+e- Clean tests!
  - $h\rightarrow ZZ,WW$ angular analysis
  - $h \rightarrow tt$ interference with QED background, lepton charge asymmetries
  - Linear polarization
- Rare decay modes
  - $H\rightarrow\gamma\gamma$!, $H\rightarrow\gamma Z$? — Difficult in e+e-
- Discovery reach for H,A
  - Up to 0.8 $\sqrt{s_{ee}}$ for $\sqrt{s_{ee}}$ ~ 800 GeV — e+e-:$\sqrt{s}/2$- 50 GeV

Anomalous couplings

A. Manteuffel

Anomalous Couplings in γγ→WW

Gauge and gauge-Higgs anomalous couplings

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

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

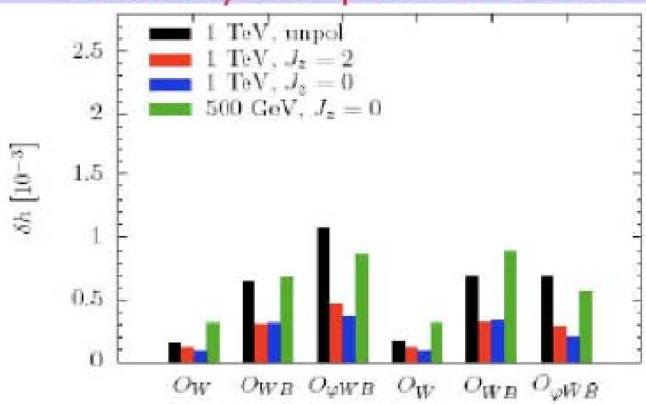
$$O_{\varphi W} = \frac{1}{2}\left(\varphi^\dagger \varphi\right) W_{\mu\nu}^i W^{i\,\mu\nu}, \qquad O_{\varphi \tilde{W}} = \left(\varphi^\dagger \varphi\right) \tilde{W}_{\mu\nu}^i W^{i\,\mu\nu},$$

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

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

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

Sensitivity with polarized beams



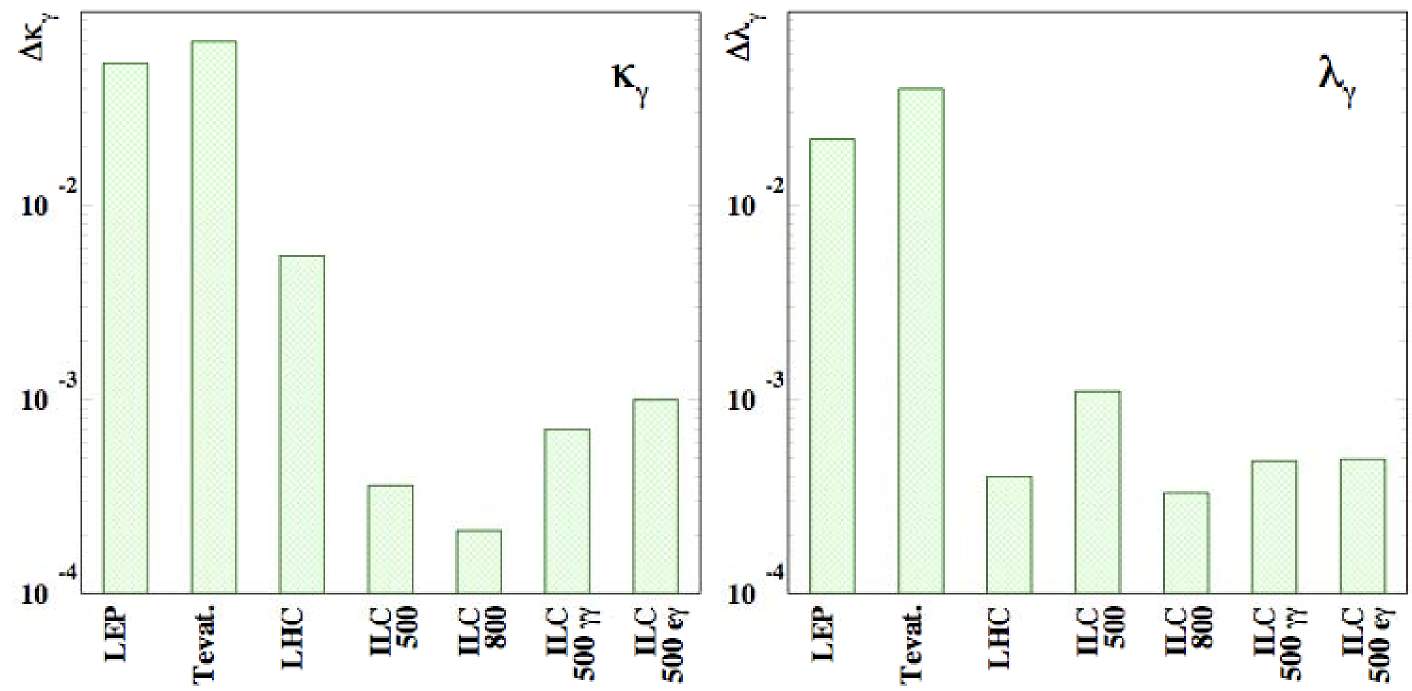
Comparison of Sensitivities

	LEP & SLD (*) $h_i\ [10^{-3}]$	$ee \to WW$ (*) $\delta h_i\ [10^{-3}]$	$\gamma\gamma \to WW$ unpolarised $\delta h_i\ [10^{-3}]$	$\gamma\gamma \to WW$ $J_z = 0$ $\delta h_i\ [10^{-3}]$
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

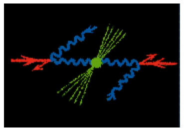
See next talk!

Anomalous WWγ couplings

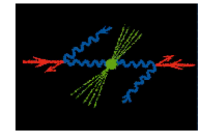
K. Moenig et al. arXiv:physics/0601204



Sensitivity to anomalous WWγ for different machines



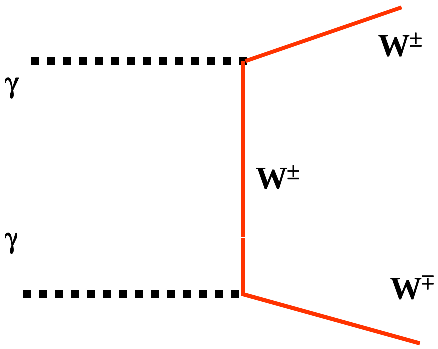
Triple Gauge Couplings



Study $\gamma\gamma \to WW$ $e\gamma \to W\nu$

Sekaric, Moenig
Bosovic, Anipko

Measure the gauge couplings with high precision



real /parasitic	$E_{e\gamma}$= 450 GeV $\int L\Delta t$=110 fb^{-1}	$E_{\gamma\gamma}$= 400 GeV $\int L\Delta t$=110 fb^{-1}	E_{ee}= 500 GeV $\int L\Delta t$=500 fb^{-1}
ΔL	0.1%	0.1%	
$\Delta\kappa_\gamma \cdot 10^{-4}$	9.9	6.7	3.1
$\Delta\lambda_\gamma \cdot 10^{-4}$	2.6	(6.0) prelim	4.3

sensitivity ~ proportional to the momentum of the particles involved in the triple gauge boson vertex

Analysis includes detector simulation/3D fits/azimuthal decay angle

Studies starting for quartic couplings in $\gamma\gamma \to WW$ and $\gamma\gamma \to WWZ$ I Marfin
Use of optimal variables F. Nagel et al.

Anomalous Top Couplings

Search for deviations in the top couplings

eγ gives good Sensitivity (1 year running)
Boos et al.

	f_2^L	f_2^R
Tevatron ($\Delta_{sys.} \sim 10\%$)	$-0.18 \div +0.55$	$-0.24 \div +0.25$
LHC ($\Delta_{sys.} \sim 5\%$)	$-0.052 \div +0.097$	$-0.12 \div +0.13$
e^+e^- ($\sqrt{s}_{ee} = 0.5$ TeV)	$-0.025 \div +0.025$	$-0.2 \div +0.2$
γe ($\sqrt{s}_{ee} = 0.5$ TeV)	$-0.045 \div +0.045$	$-0.045 \div +0.045$
γe ($\sqrt{s}_{ee} = 2$ TeV)	$-0.008 \div +0.008$	$-0.016 \div +0.016$

The γe collider is more than competitive!

f_2^L & f_2^R anomalous terms in the eff. Langrangian, $\propto 1/\Lambda$ (new physics scale)

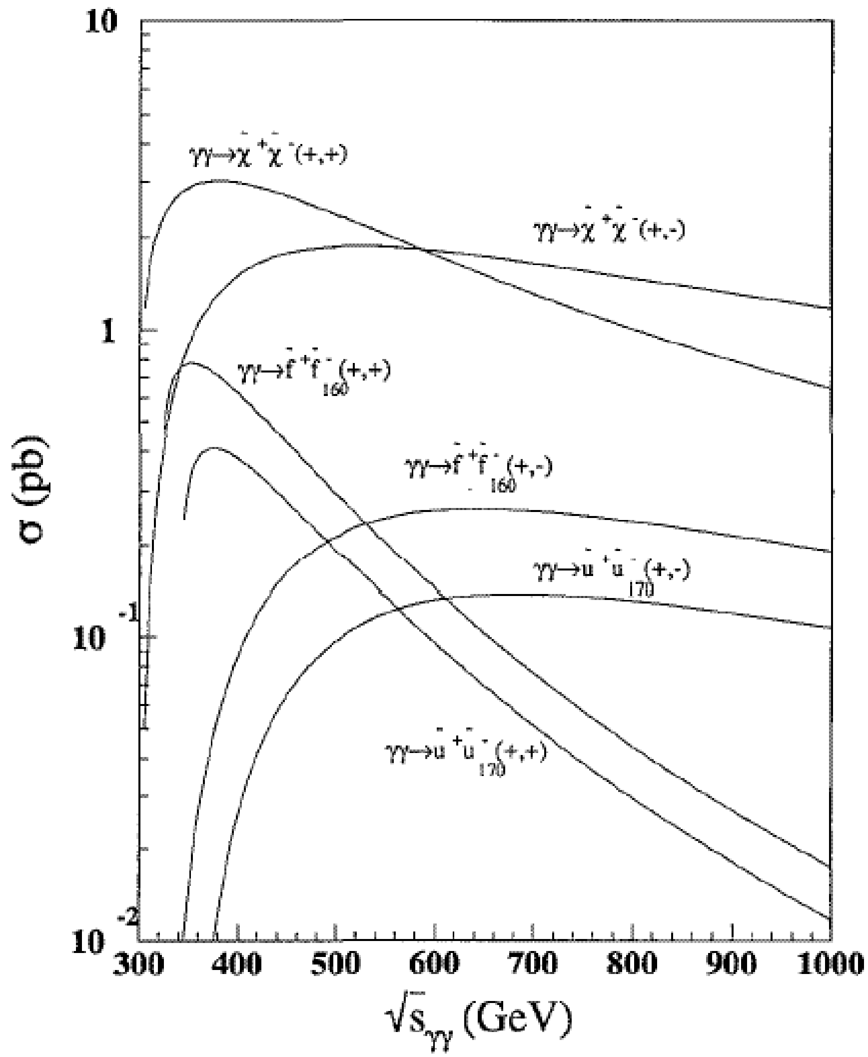
$\gamma\gamma \to tt$
Electric dipole moment
Godbole et al.

Beam energy: 250 GeV. L=20 fb^{-1}. Cut-off angle 30 deg.

No. of events	Charge asymmetry	Limit on dipole Moment
Ideal: 533	-0.031	6.5 X 10^{-17} ecm
Zarnecki: 238	-0.023	1.3 X 10^{-16} ecm

Limits will better by factor 5 for 500 fb^{-1}.

Supersymmetry



Cross sections for SUSY particles at a LC

Note: couplings only to photon

E.g. charginos at 150 GeV

	$\int \mathcal{L}_{th}$ ($\mathrm{fb}^{-1}/10^7$ s)	σ (fb)	Event yield
Spin-0	30	3000	90,000
Spin-2	5	1000	5,000
e^+e^-	160	300	48,000

Two times as many events in $\gamma\gamma$!

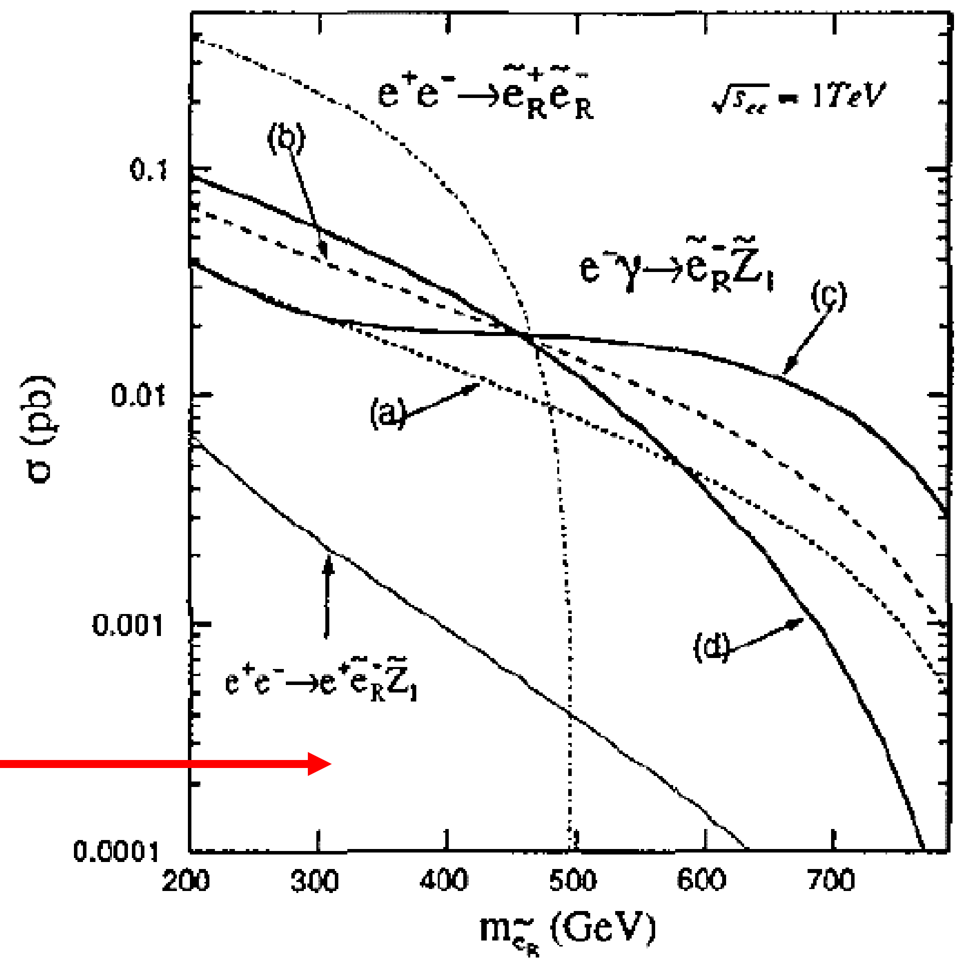
Extend reach for sleptons

e+e-: reach is √s/2
eγ: reach is 0.8√s-M(LSP)

Can extend the mass range by 100-200 GeV if LSP is light

$$e^-\gamma \to \tilde{e}_{L,R}\chi_1^{(0)} \to e^-\chi^{(0)}\chi^{(0)}$$

M(LSP) = 100 GeV



Klasen, Berge

Extend reach for sleptons

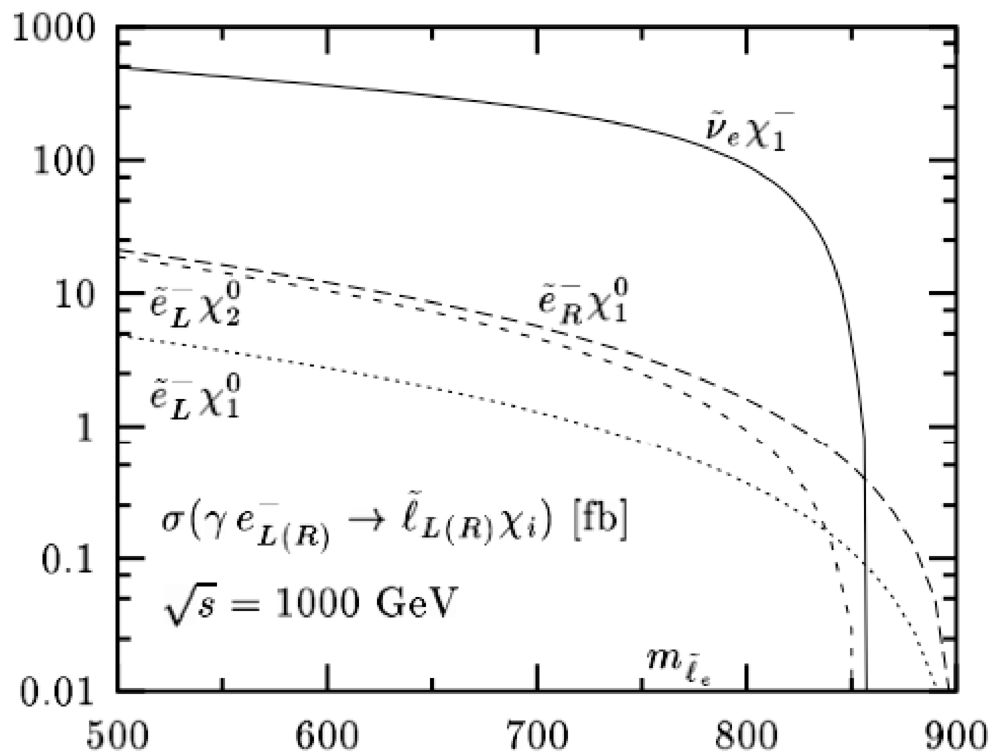
e+e-: reach is √s/2

eγ: reach is 0.9√s-M(LSP)

Can extend the mass range by 100-200 GeV if LSP is light

$$e^-\gamma \rightarrow \tilde{e}_{L,R}\chi_1^{(0)} \rightarrow e^-\chi^{(0)}\chi^{(0)}$$

M(LSP) = 100 GeV



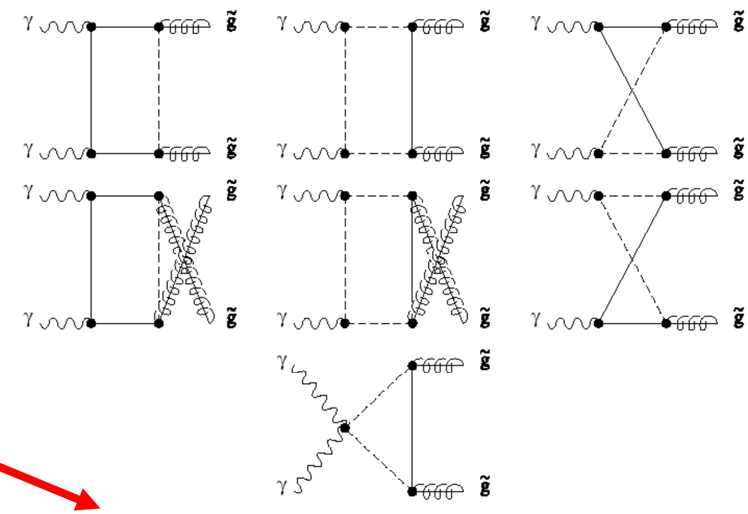
Datta, Djouadi, Muhlleitner

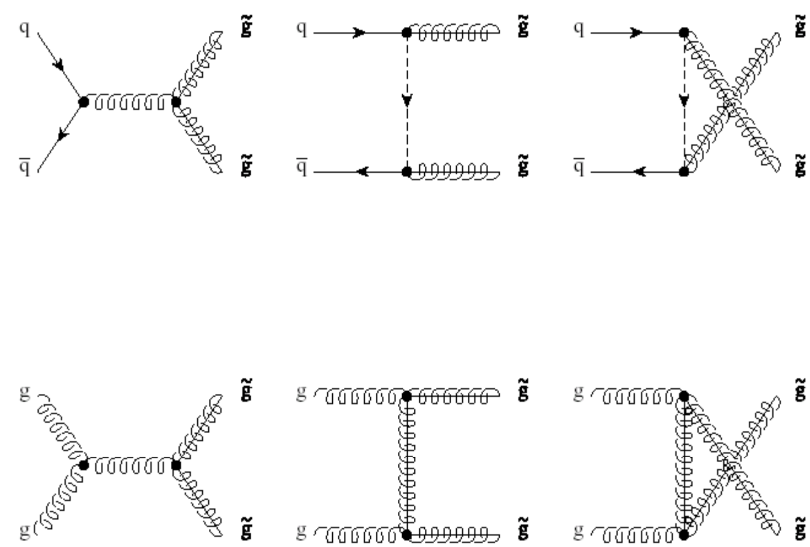
Klasen, Berge

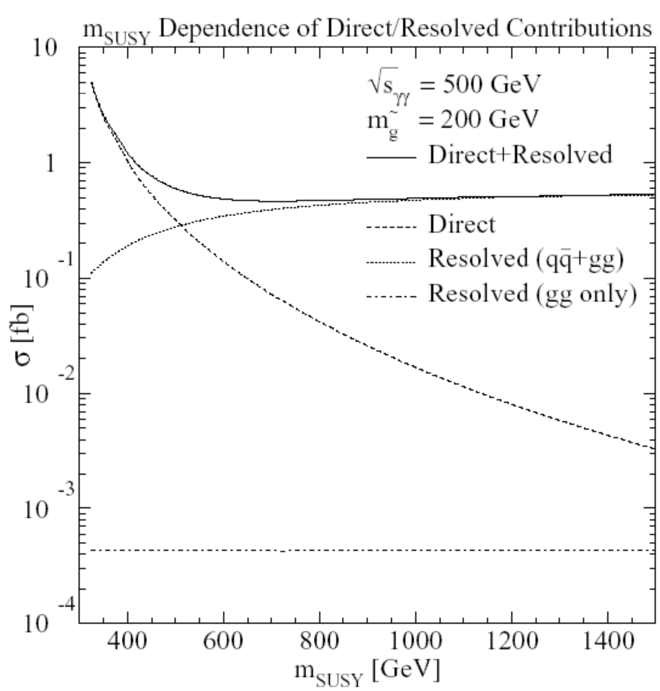
Gluino production

Berge, Klasen

Gluinos couple only strongly!
Suppressed in e+e- and cannot be measured
Can be produced at
- the loop level in direct $\gamma\gamma$ collisions
- the tree level in resolved $\gamma\gamma$ collisions



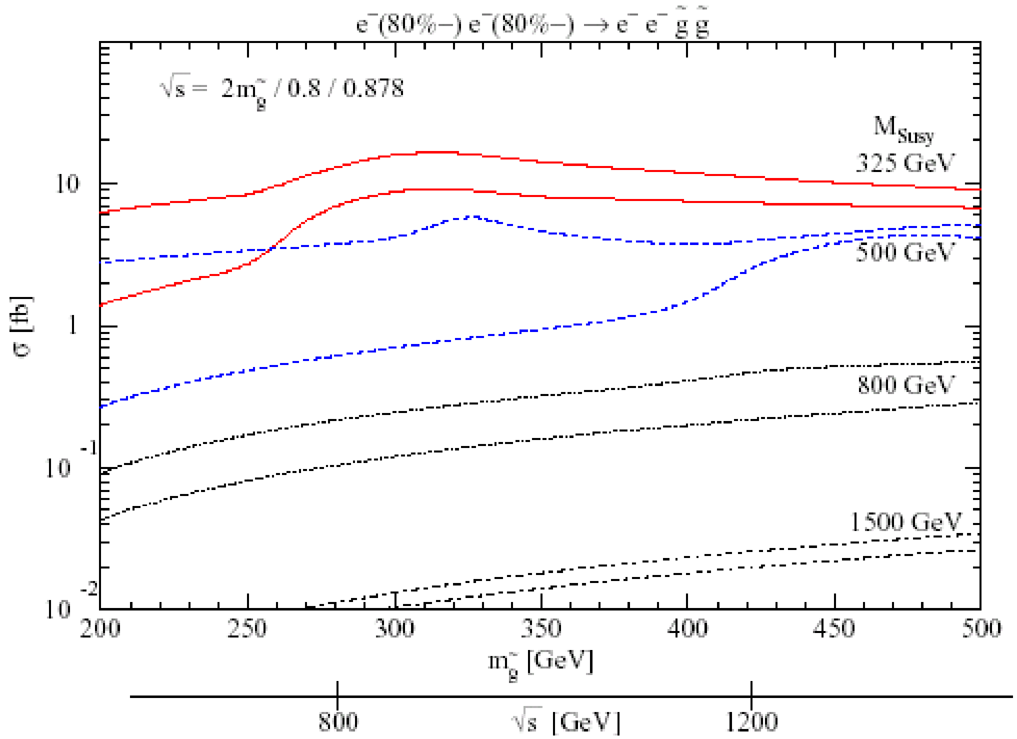




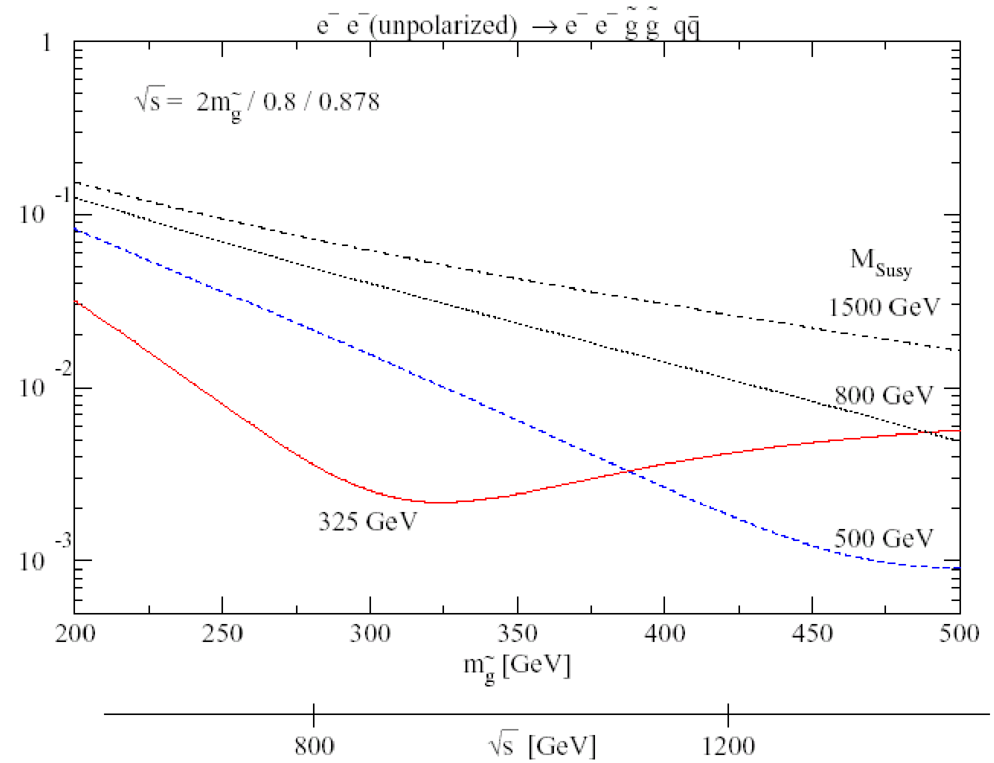
= squark mass

Gluino Production

γγ→ Gluinos (Direct)



γγ→ Gluinos (Resolved)



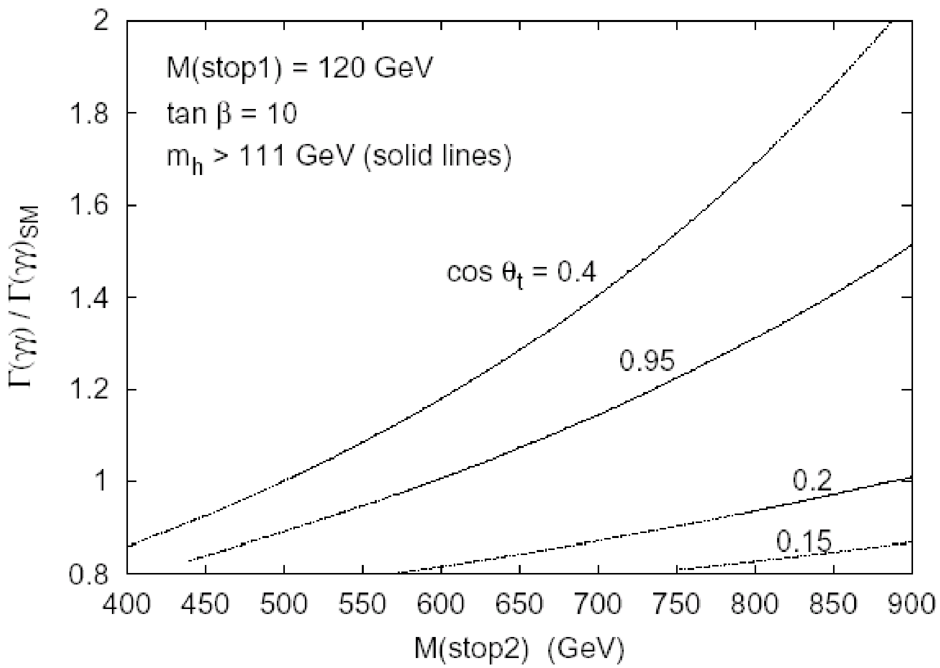
– between 20 events for squarks of 800 GeV and 2000 events per year for light squarks of 325 GeV

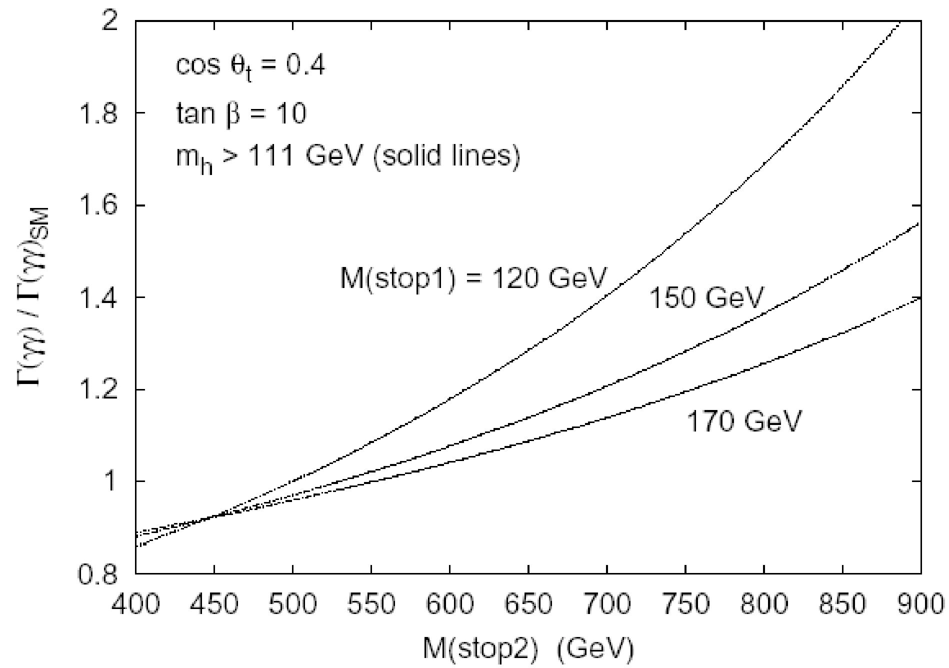
– about 20 events per year for heavy squarks (1500 GeV) by resolved contribution

Can PLC add to LHC?

Constrain mass of stop-2

Assume M(stop1) known and the stop mixing angle known from e+e-
Assume M(stop2)-M(stop1) large
$\Rightarrow$ Constrain M(stop2) from two photon partial width (yes the Higgs again!)





In favorable scenarios: can reach precision of ΔM(stop2) ~ 20 GeV

D. Asner et al.

Determination of Tanβ

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

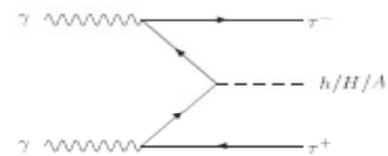
Additional methods strongly required for precision analysis of $\tan\beta$ 2

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

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 $\tan\beta$

$A\tau\tau = \tan\beta$, $H\tau\tau \simeq \tan\beta$ for A, H heavy

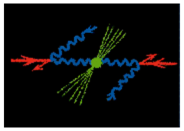
$h\tau\tau \simeq \tan\beta$ A light

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

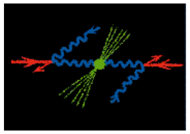
In analysis tan beta 10-50 and mass 100 -500 GeV

$\Delta \tan\beta \sim 0.9\text{-}1.3$

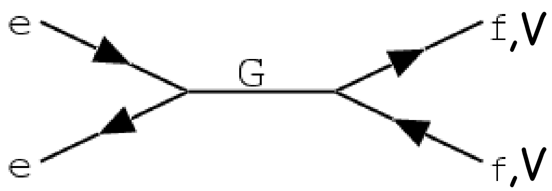
lum 100 (200) fb^{-1} for energy 500 (1000) GeV (background included)



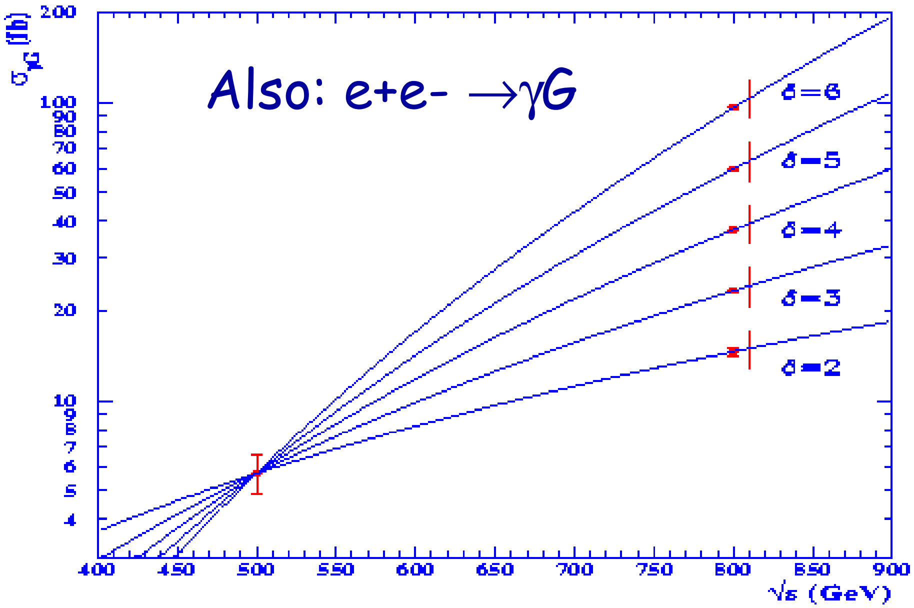
Extra Dimensions at an e+e- and photon collider



Example: Deviations from SM due to virtual Kaluza Klein Graviton effects



Exchanging (towers of) gravitons between SM particles will generate effective contact interactions, carrying spin 2



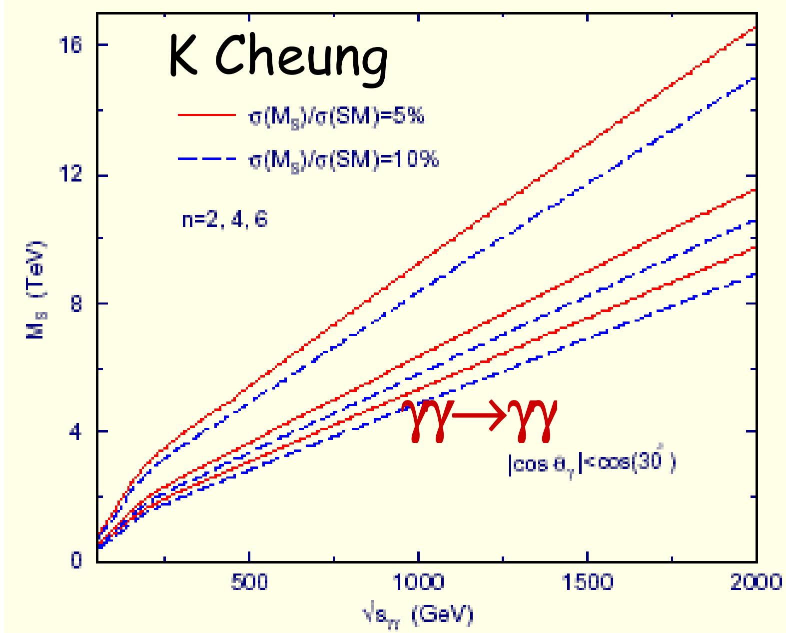
These may lead to substantial deviations from the predictions of the SM for cross sections and angular polarizations

Extra Dimensions

Why is gravity weak?
Has more than 4 dimensions to spread out
Extra dimensions small, μm to TeV^{-1} scale

⇒ Deviations in SM cross sections

ADD: Planck scale in TeV range
Photon collider has a large sensitivity



Reaction	M_S Reach (TeV units) for $L = 100\text{fb}^{-1}$
$e^+e^- \to f\bar{f}$	$6.5\sqrt{s}$
$e^+e^- \to e^+e^-$	$6.2\sqrt{s}$
$e^-e^- \to e^-e^-$	$6.0\sqrt{s}$
$pp \to \ell^+\ell^-$ (LHC)	5.3
$pp \to jj$ (LHC)	9.0
$pp \to \gamma\gamma$ (LHC)	5.4
$\gamma\gamma \to \ell^+\ell^-/t\bar{t}/jj$	$4\sqrt{s}$
$\gamma\gamma \to \gamma\gamma/ZZ$	$4-5\sqrt{s}$
$\gamma\gamma \to W^+W^-$	$11\sqrt{s}$

T.Rizzo

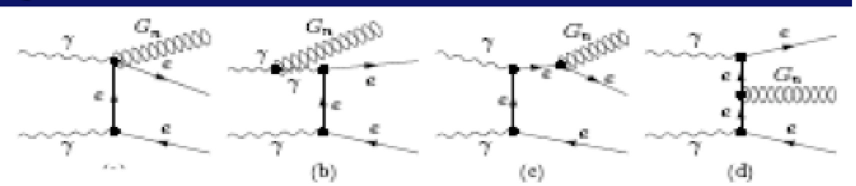
WW production:
-Large statistics
-Many observables

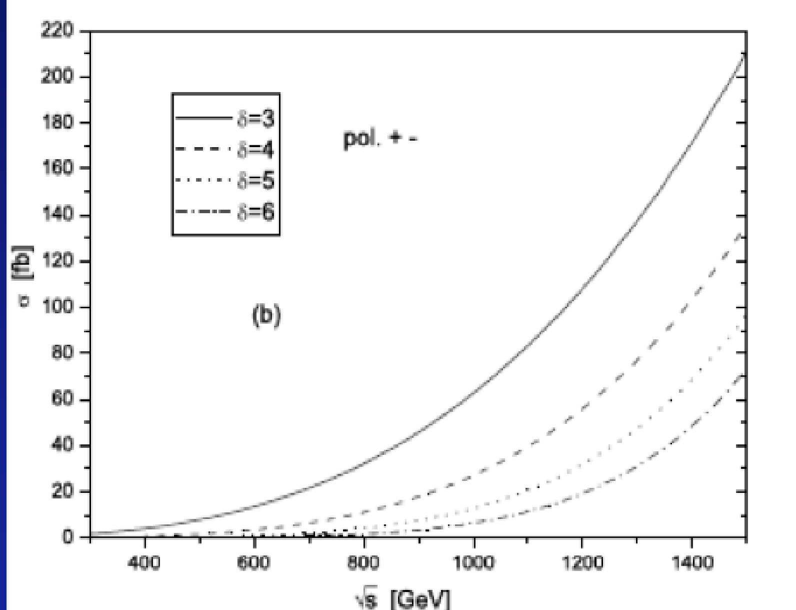
Also studies on Radions in RS-models

Extra Dimensions

Using luminosity measurements 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

Extra dimensions

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

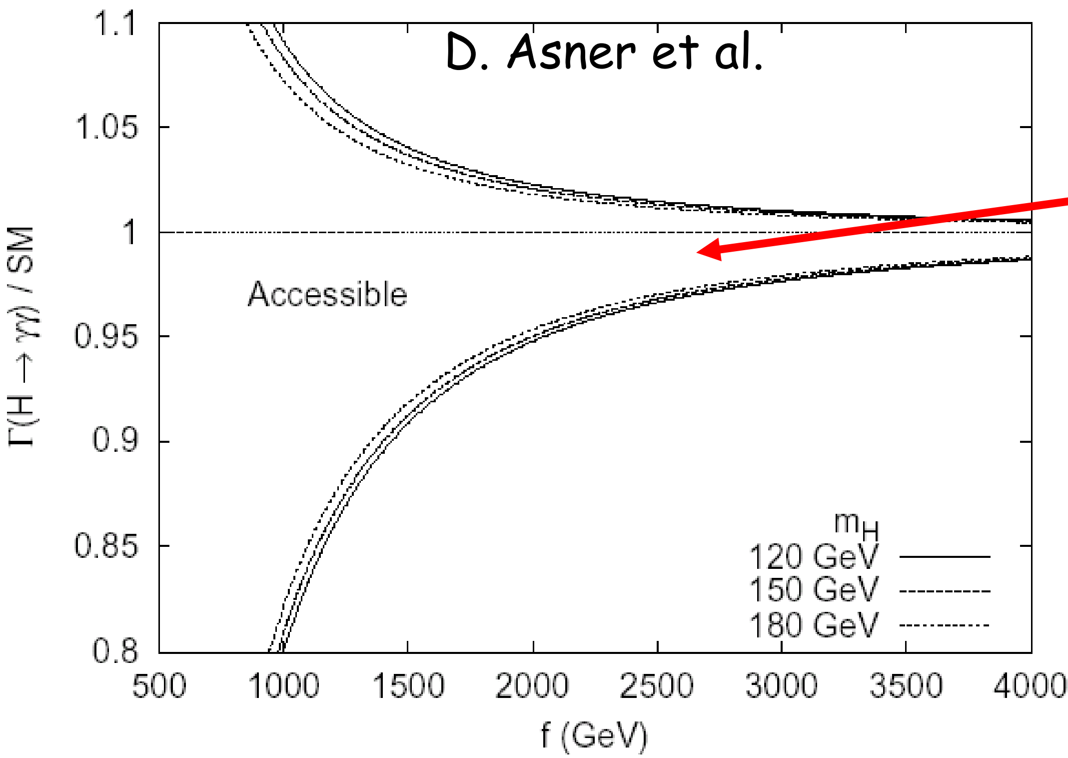
Full bakground simulation

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 $M_S \leq 2.67$ TeV, while in the case of $\sqrt{s} = 500$ GeV, the graviton signal can be detected only when $M_S \leq 1.40$ 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.

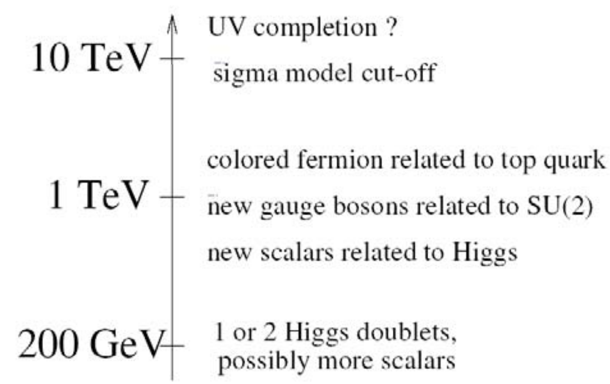
Little Higgs Model

Another alternative to SUSY:
Stabelizing the Higgs with new weakly coupled fermions and Gauge bosons
Expect 'new top' quark around 1 TeV, and new W,Z at somewhat higher masses

Littlest Higgs model: symmetry broken due to vacuum condensate f ~$\Lambda/4\pi$

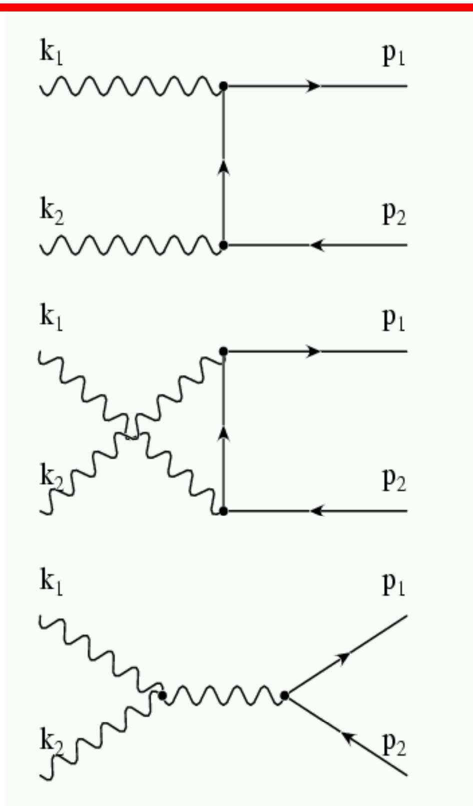


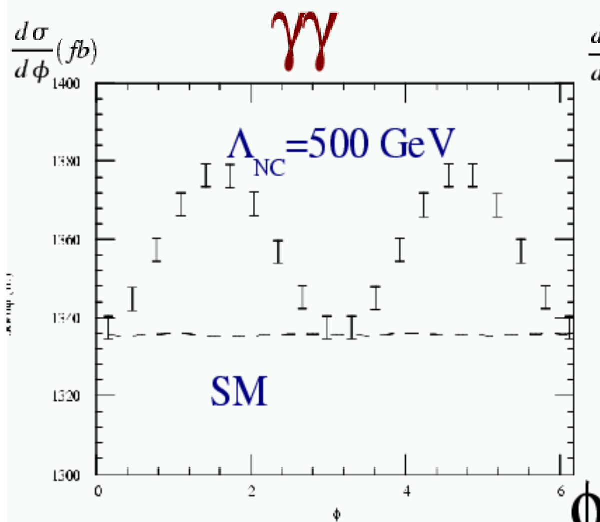
Sensitivity to f at a PC, by measuring the partial width of the Higgs

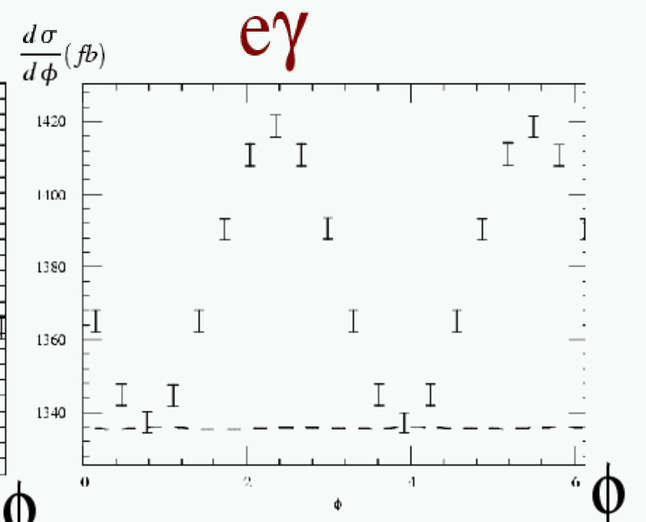


Non-commutative theories

Breakdown in QED due to preferred direction in space: azimuthal effects







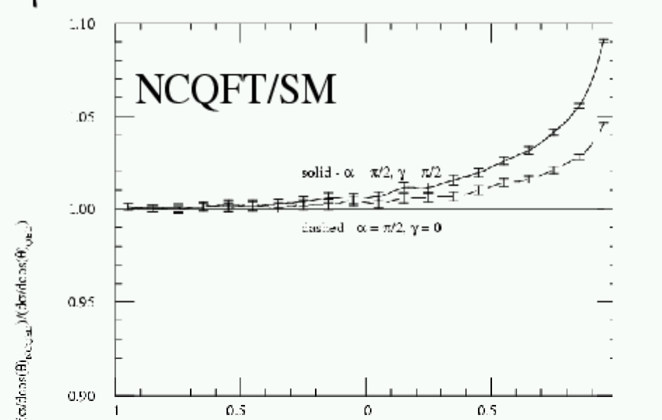
Pair-Production (γγ):

-space-time non-commutivity

Compton-Proces (eγ):

-space-space and space-time non-commutivity

Λ_{NC} sensitivity similar to Bhabha process but different combination of NC matrix elements tested



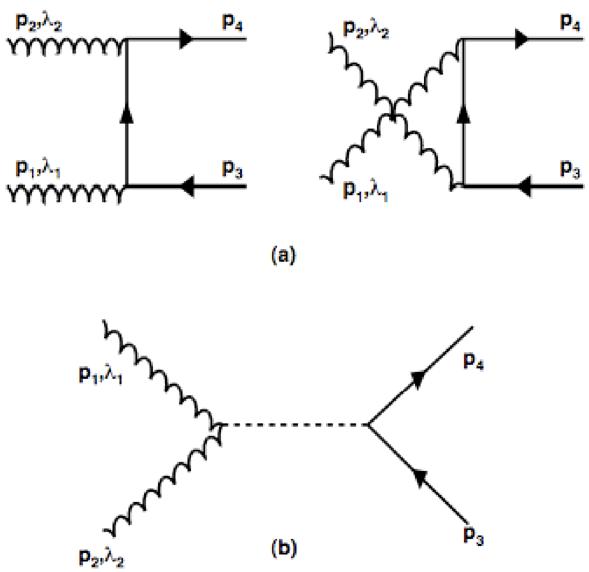
cosθ

this study:

p_T>10 GeV, $10^0<\theta<170^0$, L_{ee}=500 fb^{-1}

J. Hewett et al

Unparticles



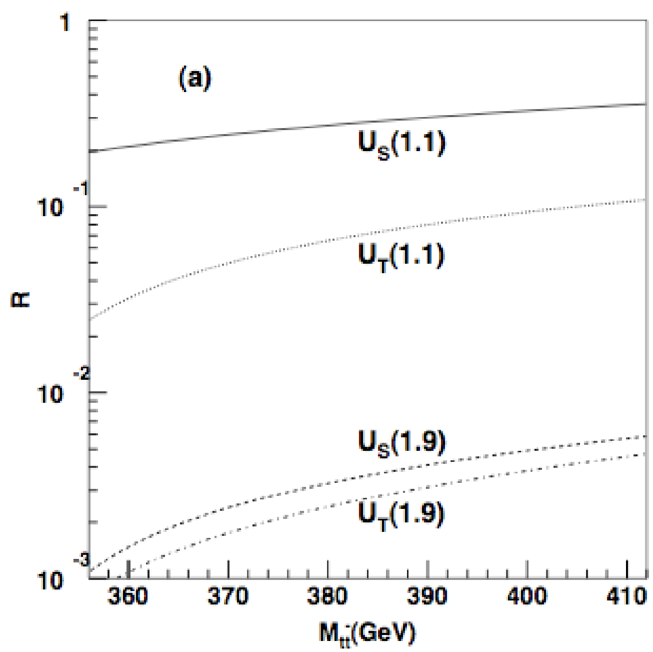
$$R_{\mathcal{U}}^{S(T)} = \frac{\sigma_{SM+\mathcal{U}}^{S(T)} - \sigma_{SM}}{\sigma_{SM}},$$

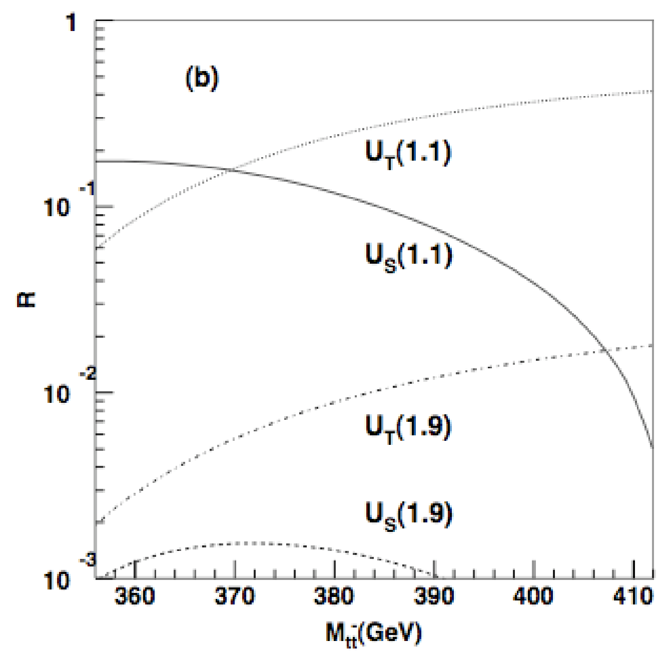
arXiv:0802.0236

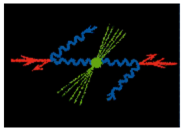
Effect of virtual unparticle contribution to the γγ→tt cross section

Measurable effects

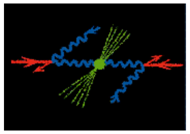
Also γγ→γγ
See arXiv:0801.0018







Conclusions



Many detailed studies on the physics case for the photon collider

- R&D for a photon collider & detectors ⇒ V. Telnov/J. Gronberg
- Detail results on physics
  - QCD studies on the structure of the photon and $\sigma(\gamma\gamma)_{tot}$
  - The light Higgs results confirmed and extended → $\Delta\Gamma_{\gamma\gamma}/\Gamma_{\gamma\gamma}$ ~ 2%
  - Higgs channels in WW,ZZ studied → $\Delta\Gamma_{\gamma\gamma}/\Gamma_{\gamma\gamma}$ ~ 3-10%
  - H/A study confirms reach for high masses, beyond e+e-
  - Potential for CP, Higgs spin etc → studies starting
  - Detailed study of the TGCs → λ measurement competitive with e+e-
  - Excellent sensitivity to SUSY and Extra Dimensions/alternative theories

- A photon collider is an excellent machine for physics
- It is strongly coupled to the faith of ILC/CLIC and hence >2020
- Some of its program can be probably be explored at the LHC with two-photon physics studies

Backup

Timeline for ILC options?

Year: 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29

EDR	Site	Construction	e+e- physics	options

Concrete starts to be poured
Decision are made that we will have to live wit

Photon collider?
Is the community in place?

First Physics from LHC
Our view of what needs to be done will be refined, perhaps changed

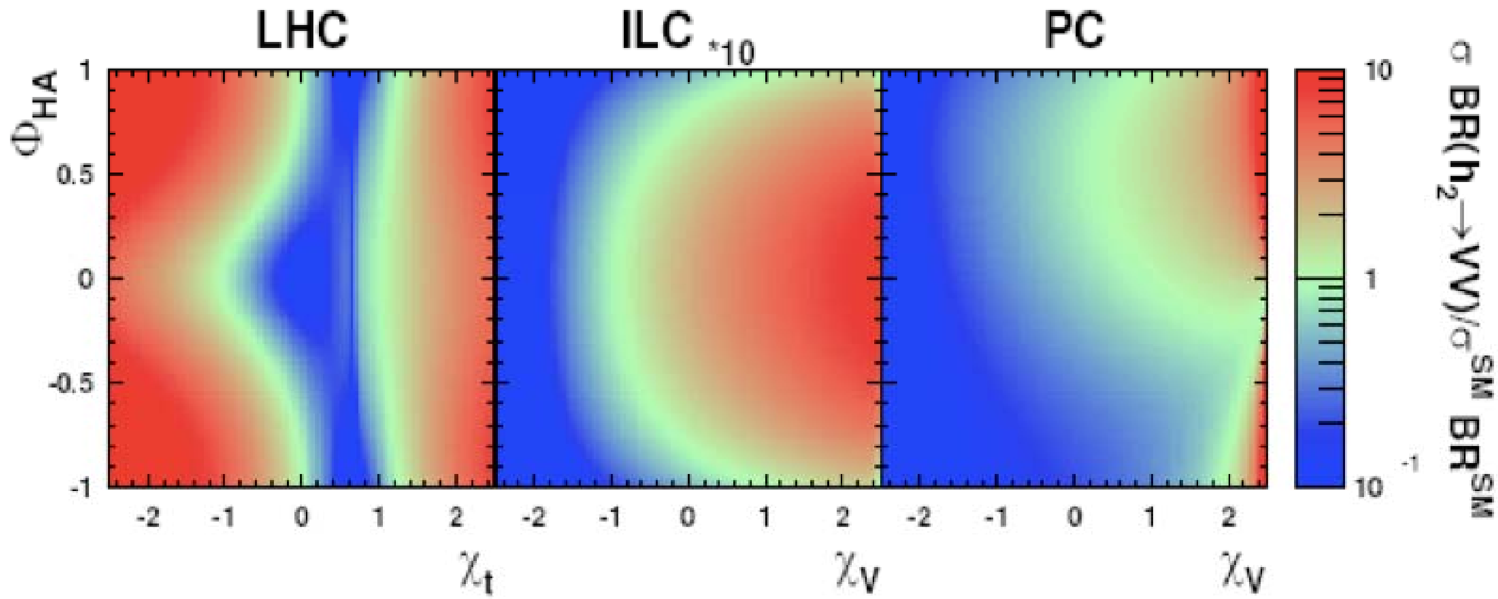
We need to be ready to make decisions for the baseline machine to maximize it's physics potential for the long term.

J. Gronberg LCWS07

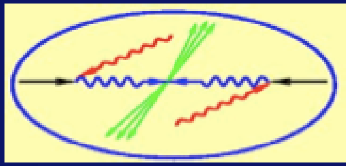
LHC $\oplus$ ILC $\oplus$ PC

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

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



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

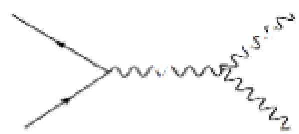


- Resonance production of C=+ states (eg. Higgs) Ginzburg et al
- Higher mass reach Spira, Zerwas
- Polarised beams – CP filter Gunion, Grzadkowski,Hagiwara, Godbole, Zarnecki
- H $\gamma\,\gamma$ coupling – sensitivity to charged particles in theory (nondecoupling) Ginzburg et al.., Gunion..
- Direct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

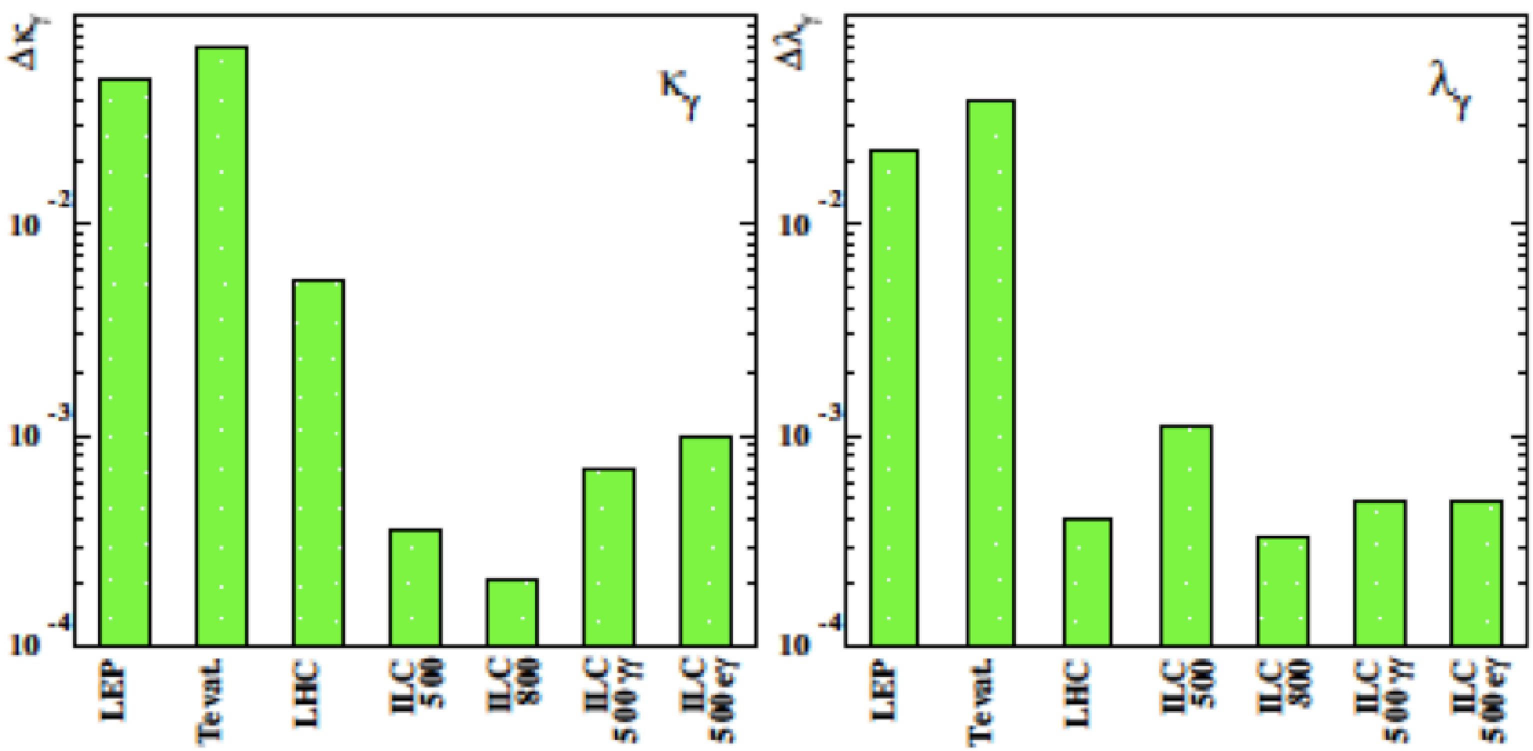
Coupling of Gauge Bosons at LHC, ILC,PLC

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

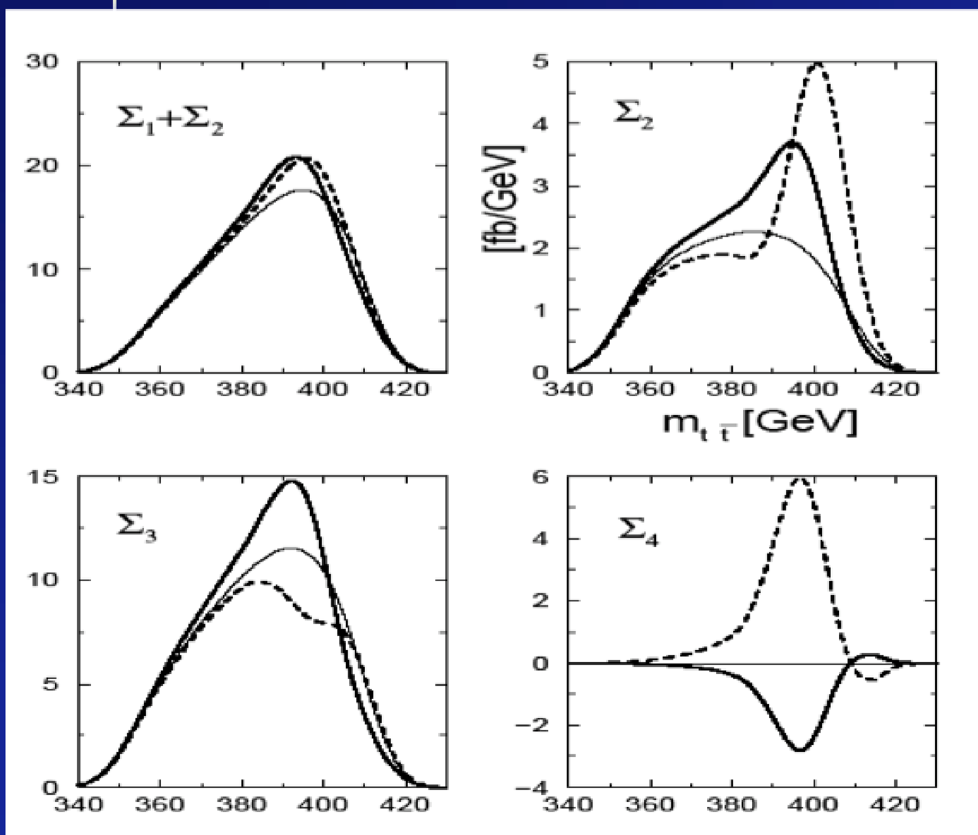
anomalous couplings
(V_mu nu and dual)



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



CP-even, CP-odd states in $\gamma \gamma \to t\ t$ Asakawa, Hagiwara.. 2000-



Scalar (dashed)

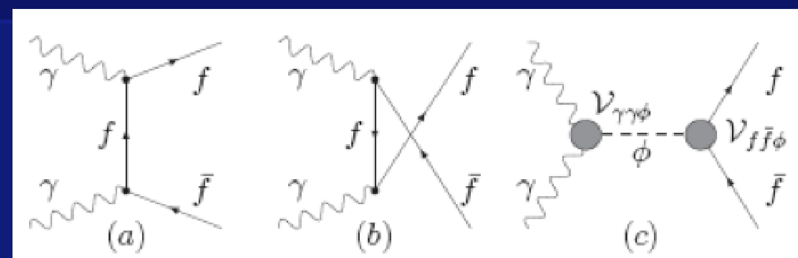
Pseudoscalar (thick)

Mass – 400 GeV

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

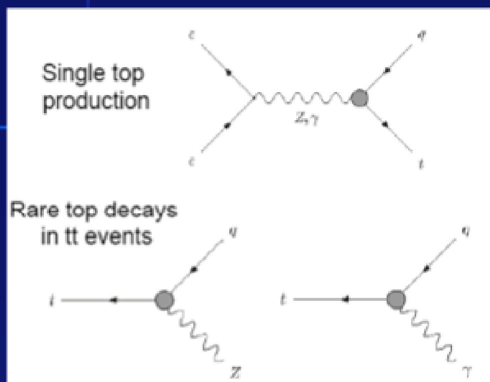
In contrast to VV case – typically A_V dominates

Top FCNCs

Top FCNC's

A. Hoang, Florence, Sept.07

Yang, hep-ph/0409351
Aguilar-Saavedra, hep-ph/0409342



$\sqrt{s} = 500$ GeV	SM	2HDM-III	MSSM	TC2
$\sigma(\gamma\gamma \to t\bar{c})$[fb]	$\mathcal{O}(10^{-8})$	$\mathcal{O}(10^{-1})$	$\mathcal{O}(10^{-1})$	$\mathcal{O}(10)$
$\sigma(e\gamma \to et\bar{c})$[fb]	$\mathcal{O}(10^{-9})$	$\mathcal{O}(10^{-2})$	$\mathcal{O}(10^{-2})$	$\mathcal{O}(1)$
$\sigma(e^+e^- \to t\bar{c})$[fb]	$\mathcal{O}(10^{-10})$	$\mathcal{O}(10^{-3})$	$\mathcal{O}(10^{-2})$	$\mathcal{O}(10^{-1})$
$Br(t \to cg)$	$\mathcal{O}(10^{-11})$	$\mathcal{O}(10^{-5})$	$\mathcal{O}(10^{-5})$	$\mathcal{O}(10^{-4})$
$Br(t \to cZ)$	$\mathcal{O}(10^{-13})$	$\mathcal{O}(10^{-6})$	$\mathcal{O}(10^{-7})$	$\mathcal{O}(10^{-4})$
$Br(t \to c\gamma)$	$\mathcal{O}(10^{-13})$	$\mathcal{O}(10^{-7})$	$\mathcal{O}(10^{-7})$	$\mathcal{O}(10^{-6})$
$Br(t \to cH)$	$< 10^{-13}$	$\mathcal{O}(10^{-3})$	$\mathcal{O}(10^{-4})$	$\mathcal{O}(10^{-1})$

Any signal clear indication for new physics!

ILC luminosity range

$1\ \text{fb} \Leftrightarrow 10^2 - 10^3$ events

$(\mathcal{L} = 100 - 1000\ \text{fb}^{-1})$

- production more sensitive than decay (larger phase space)
- beam polarization improves sensitivity for production

3σ discovery limits — Aguilar-Saavedra, hep-ph/0102197

	LHC	ILC	ILC+
$\text{Br}(t \to Zc)\ (\gamma_\mu)$	3.6×10^{-5}	1.9×10^{-4}	1.9×10^{-4}
$\text{Br}(t \to Zc)\ (\sigma_{\mu\nu})$	3.6×10^{-5}	1.8×10^{-5}	7.2×10^{-6}
$\text{Br}(t \to \gamma c)$	1.2×10^{-5}	1.0×10^{-5}	3.8×10^{-6}

Corresponding to one year of running time:
LHC : 100 fb^{-1}
ILC : 300 fb-1, √s=500 GeV, no beam pol
ILC+: " ,$P(e^-)$=+0.8, $P(e^+)$=-0.6

WHAT PLC CAN AND CANNOT DO (TESLA TDR'2001)

Gamma-Gamma Planners' (GGP) meeting in Kazimierz, Sept,7, 2005 (PLC2005), - based on the notes by David J. Miller

Present: V.Telnov, A.Finch, M.Krawczyk, J.Dainton, S. Maxfield, F.Kapusta, I. Ginzburg, P.M.Zerwas, F.Zarnecki, P.Pniez, K.Moenig, J.Gronberg, D.J.Miller

The $\gamma\gamma$ and $e\gamma$ upgrade options are not part of the baseline ILC design.

If provision for the PLC option is to be included in the Reference Design Report at the end of 2006, the list of issues need to be tackled and convincing arguments given before the middle of 2006, on

- Optical Cavity
- Beam Dump
- Luminosity maintenance
- Crossing Angle
- Backgrounds
- Physics

The list of processes whose study will justify the PLC option needs to be reviewed. Some vital analyses are still missing (http://photon2005.fuw.edu.pl)

A need for PLC?

Higgs physics at PLC

- Precision measurements of the light Higgs boson production (->bb) and distinguishing SM-like scenarios
- Establishing CP property of Higgs bosons
- Higher mass reach and covering LHC wedge
- Testing Higgs selfinteraction

Search for SUSY particles