Photon 2003

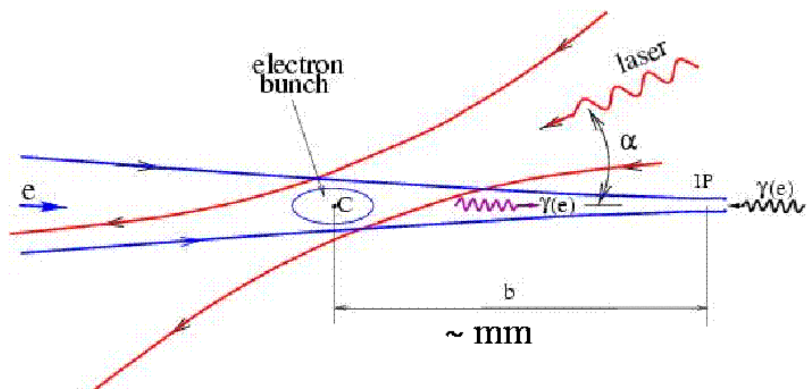
Organised by the Laboratori Nazionali di Frascati

Two Photon Physics at Future Linear Colliders

A.De Roeck

CERN

Frascati, April 2003



Linear Colliders

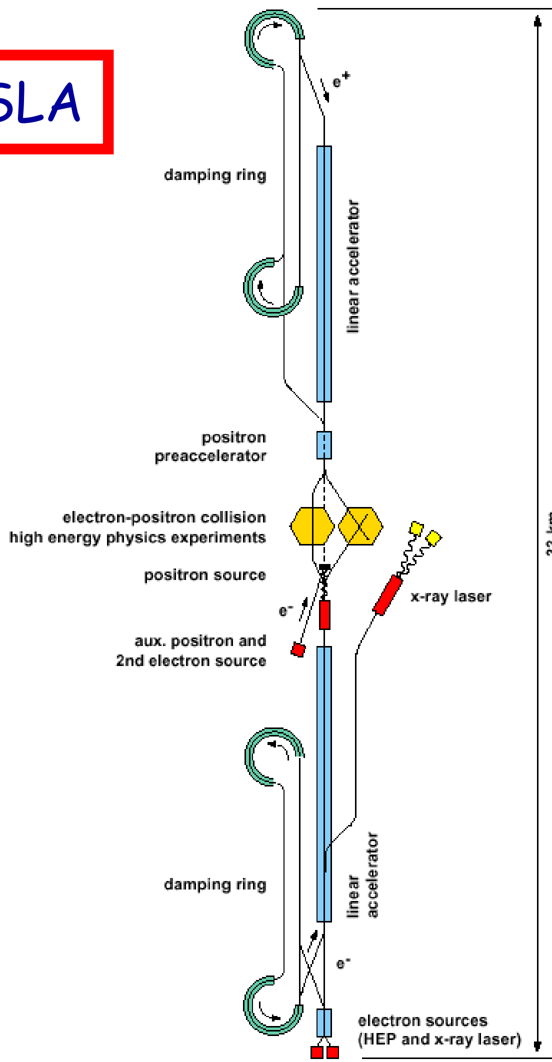
- The next machine that will probe up to the TeV scale is the LHC
  - Should settle the question on Electroweak Symmetry breaking and likely on physics beyond the SM (SUSY,…)
- World consensus: To complete the picture further a high precision machine will be needed, i.e. a e+e- collider
- Options:

TESLA	NLC/JLC	CLIC
SC	Warm RF	TBA
0.09→0.8TeV	.09→1TeV	0.09→5TeV
TDR	CDR	R&D

TESLA/NLC technology almost ready : A technology decision in 2004 ?
CERN: Development of Two-Beam acceleration scheme to reach 150 MV/m
Not ready before 2007

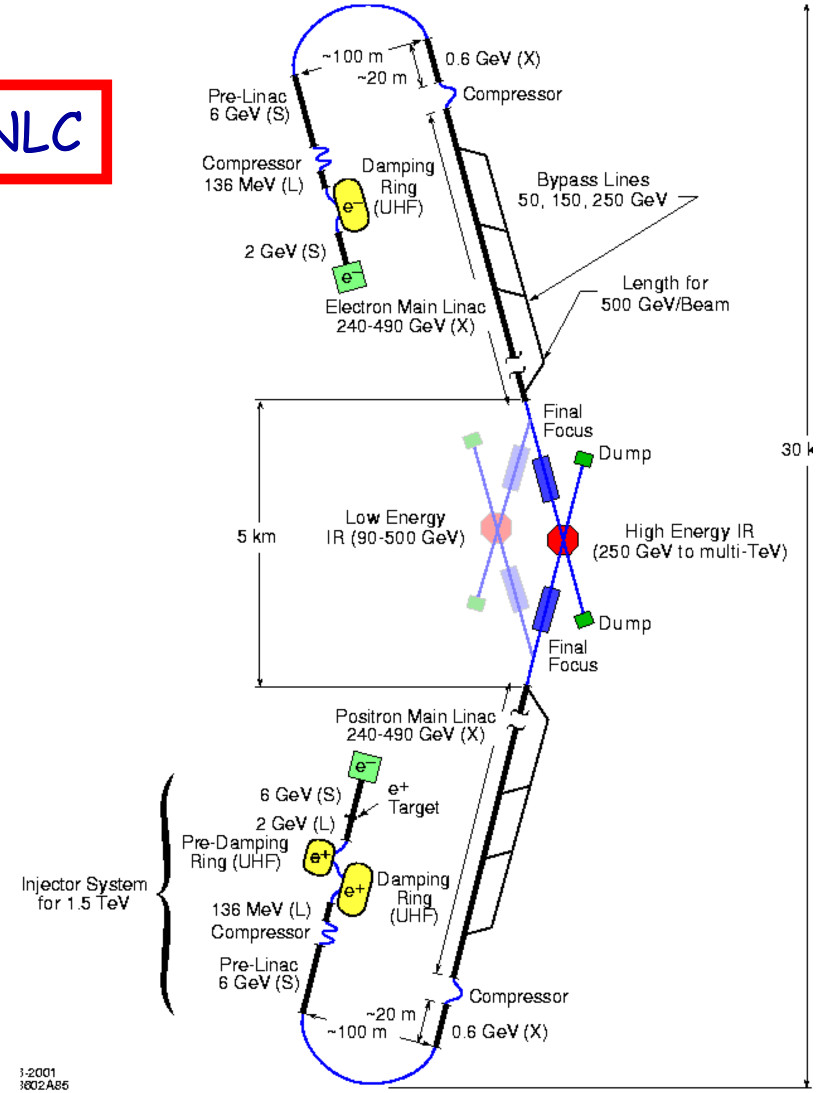
Linear e+e- colliders

TESLA



33 km

NLC



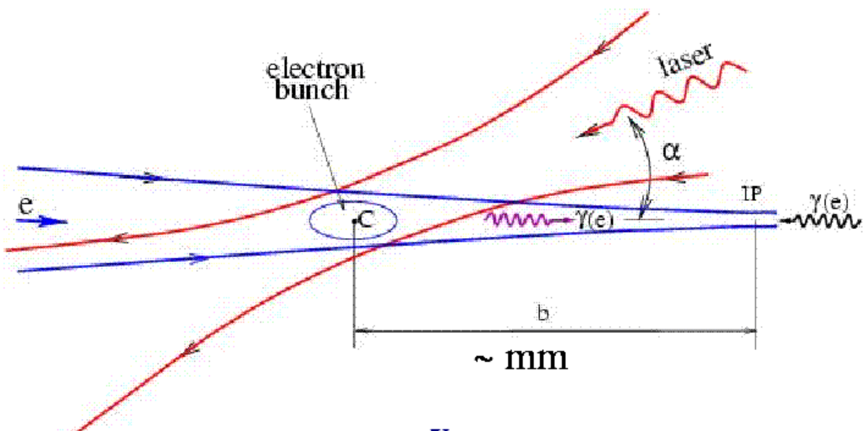
Two interaction regions foreseen… one for gamma-gamma?

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



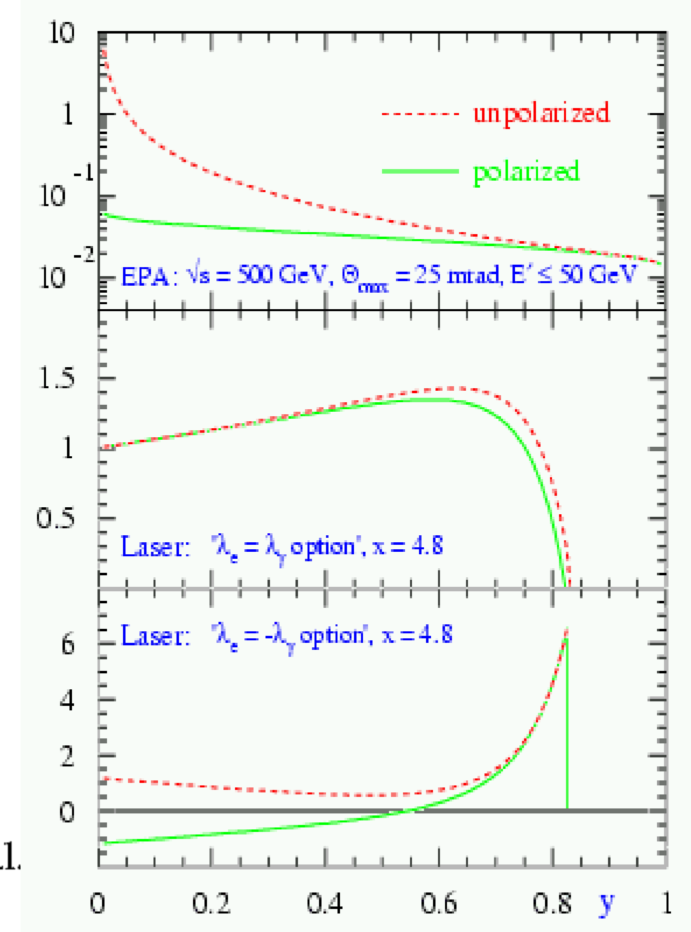
$$E_\gamma^{max} = \frac{x}{x+1} E_e$$

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

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

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

V.Telnov et al.



First discussion at Photonxx ⇒ Aachen 83 J. Field

The ECFA-DESY study

- Activities in Europe
- Photon collider workshop @ DESY June 14 (Heuer, Telnov, Walker, ADR)
- TESLA-TDR (March 2001) Appendix
- ECFA-DESY workshop 2001-2003, last meeting was last week
  - Working group on $\gamma\gamma$ /eγ collider technology
    K. Moenig and V. Telnov
  - Working group on $\gamma\gamma$ physics (http://www-h1.desy.de/~maxfield/ggcol/lcgg.html)
    M. Kraemer, M. Krawczyk, S. Maxfield, ADR, (S. Soldner-Rembold)

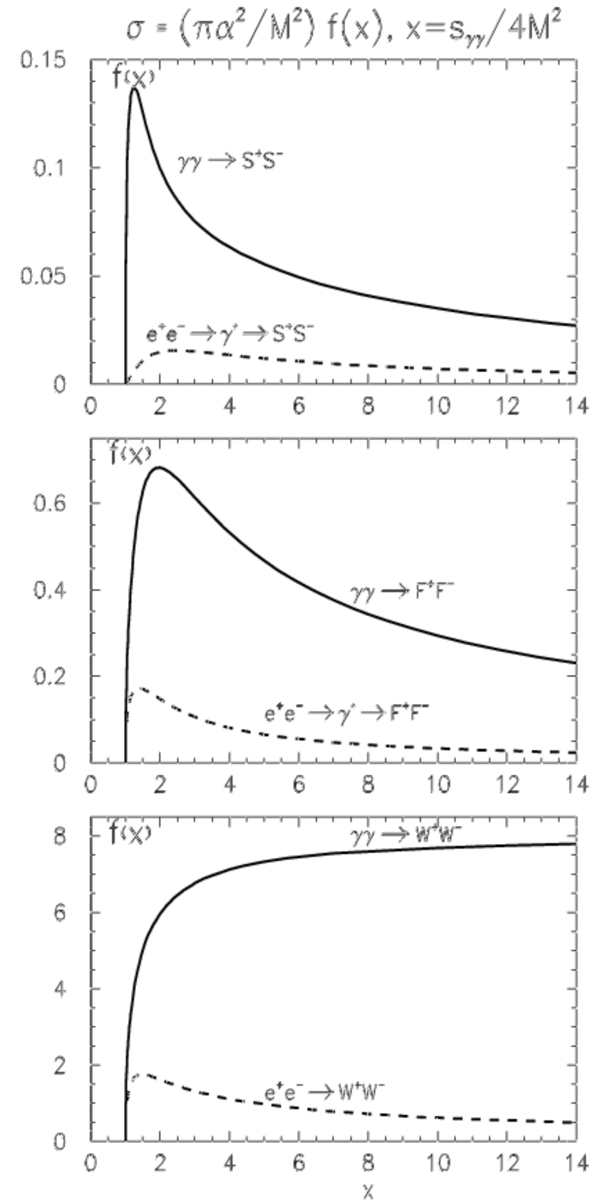
    $\Rightarrow$ Emphasis on real lumi spectra, detector simulation, backgrounds
- Activities in US (& Japan)
  - Working Group on physics Studies (M. Velasco, J. Gronberg)
    - Good contact with us in Europe
  - Working Group on physics Studies in Japan (T. Takahashi)
  - R&D for a gamma-gamma collider (J. Gronberg)
- Activities in the CLIC working group
  - Studies of $\gamma\gamma$ at 3 –5 TeV

Advantages of $\gamma\gamma$ and $e\gamma$

- 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 scenarios
- CP analysis opportunities (linear γ polarization…)
- Can test precisely couplings to photons…

$\Rightarrow$ Physics Menu

- QCD
- Higgs
- EW: e.g. Triple Gauge couplings
- Supersymmetry
- Alternative theories

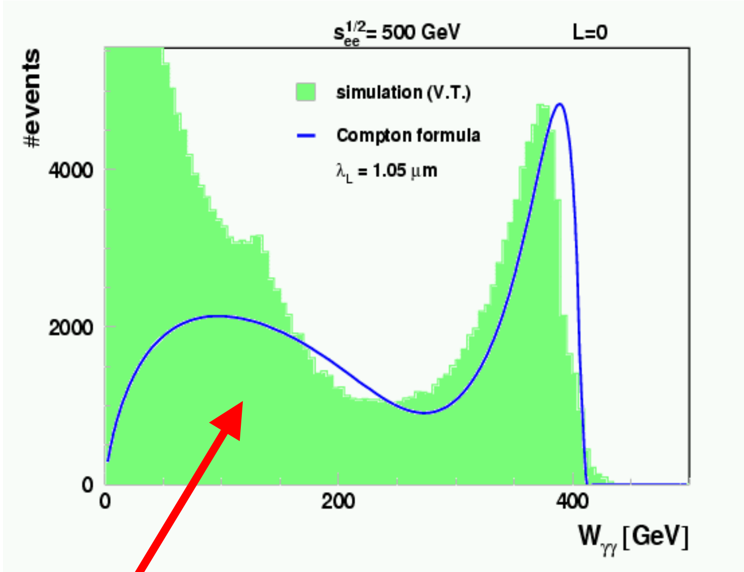


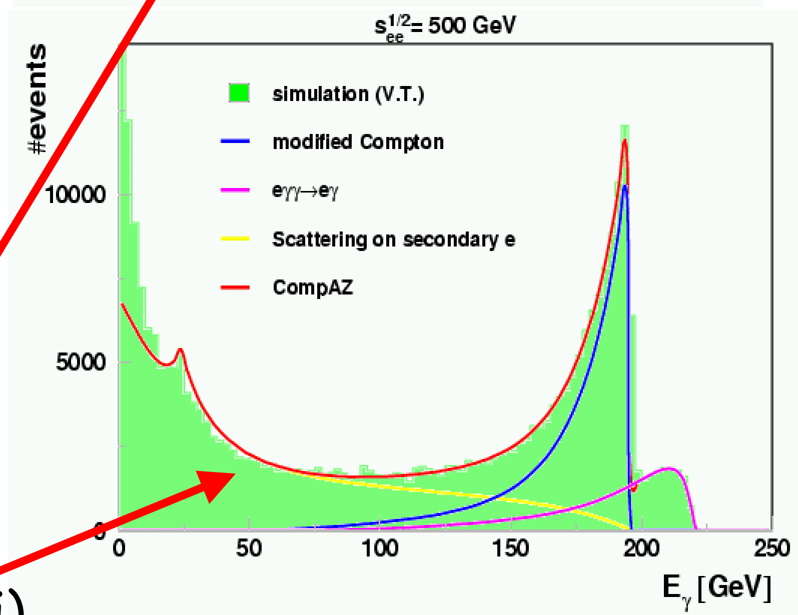
Luminosity Spectra

TDR 2001 parameters

$2E_0$ [GeV]	200	500	800
λ_L [μm]/x	1.06/1.8	1.06/4.5	1.06/7.2
t_L [λ_{scat}]	1.35	1	1
$N/10^{10}$	2	2	2
σ_z [mm]	0.3	0.3	0.3
$f_{rep} \times n_b$ [kHz]	14.1	14.1	14.1
$\gamma\epsilon_{x/y}/10^{-6}$ [m·rad]	2.5/0.03	2.5/0.03	2.5/0.03
$\beta_{x/y}$ [mm] at IP	1.5/0.3	1.5/0.3	1.5/0.3
$\sigma_{x/y}$ [nm]	140/6.8	88/4.3	69/3.4
b [mm]	2.6	2.1	2.7
$Lee\,(geom)$ [10^{34} cm^{-2}s^{-1}]	4.8	12	19
$L_{\gamma\gamma}(z > 0.8 z_{m,\gamma\gamma})$[$10^{34}$ cm^{-2}s^{-1}]	0.44	1.15	1.7
$L_{\gamma e}(z > 0.8 z_{m,\gamma e})$[$10^{34}$ cm^{-2}s^{-1}]	0.35	1.	1.6
$L_{ee}(z > 0.65)$[10^{34} cm^{-2}s^{-1}]	0.03	0.08	0.14

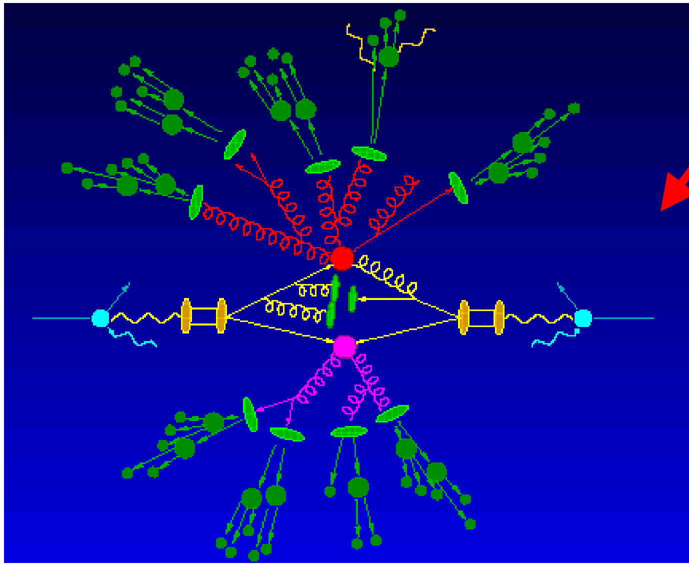
$$L_{\gamma\gamma}(z > 0.8 z_m) \sim \frac{1}{3} L_{e^+e^-}.$$



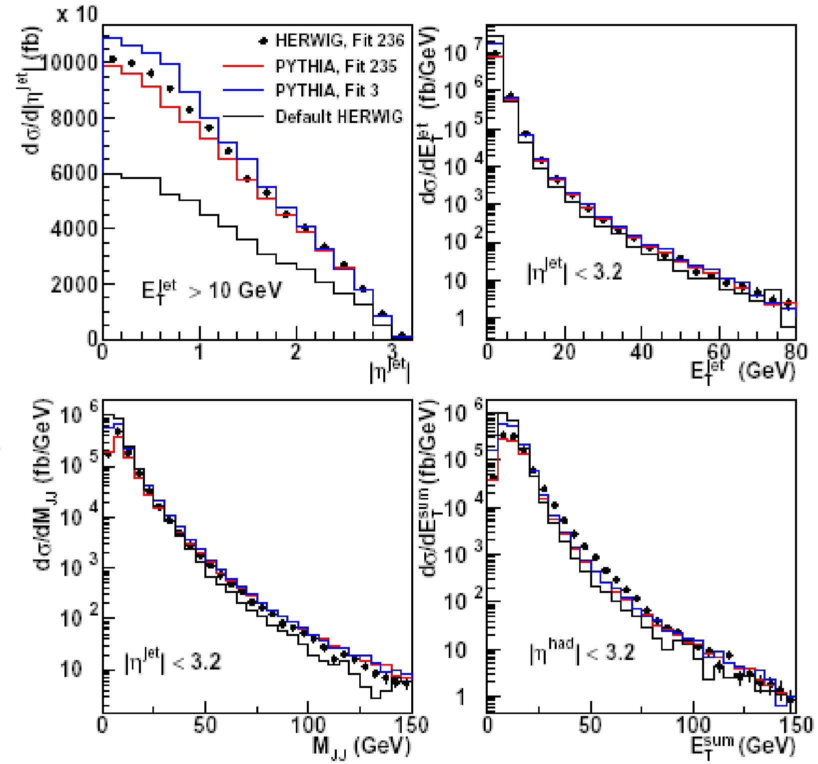


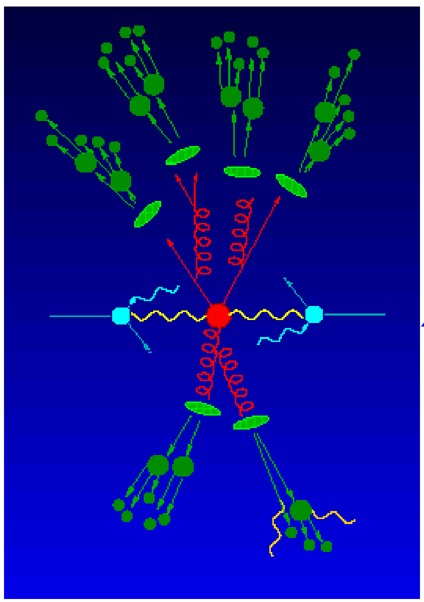
Luminosities files with PHOCOL (V. Telnov)
Can be used via CIRCE (T. Ohl)
Analytical approximation COMPAZ (A. Zarnecki)

Tools: Monte Carlos & Tuning



- SHERPA Generator framework (matrix elements, partons showers,...) (F. Kraus et al.)
- Tuning of the $\gamma\gamma$ & γp Monte Carlo models via JETWEB (J. Butterworth, M. Wing)



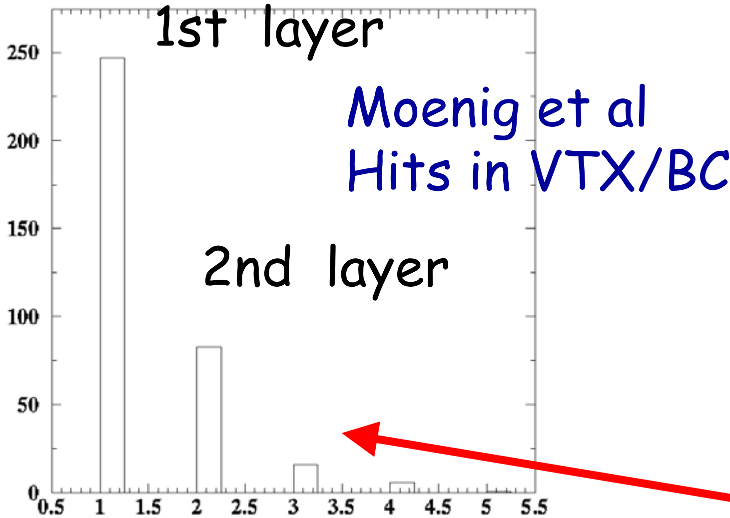


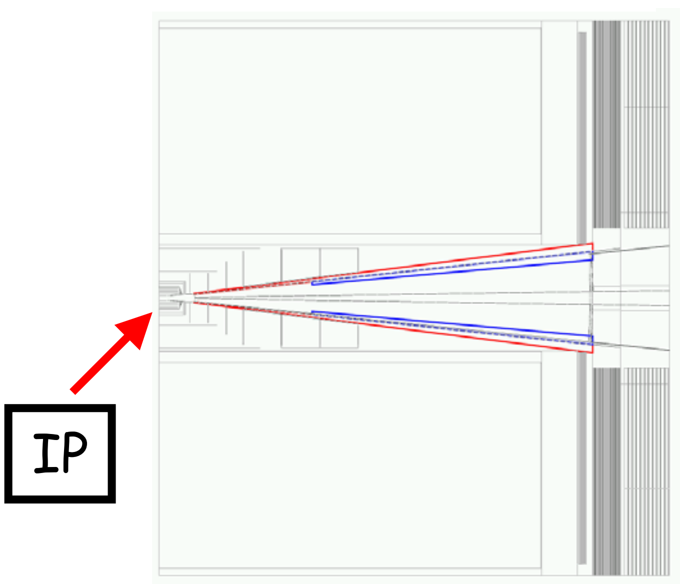
Resolved

Direct

A tune for LC $\gamma\gamma$ studies has been produced

Background studies



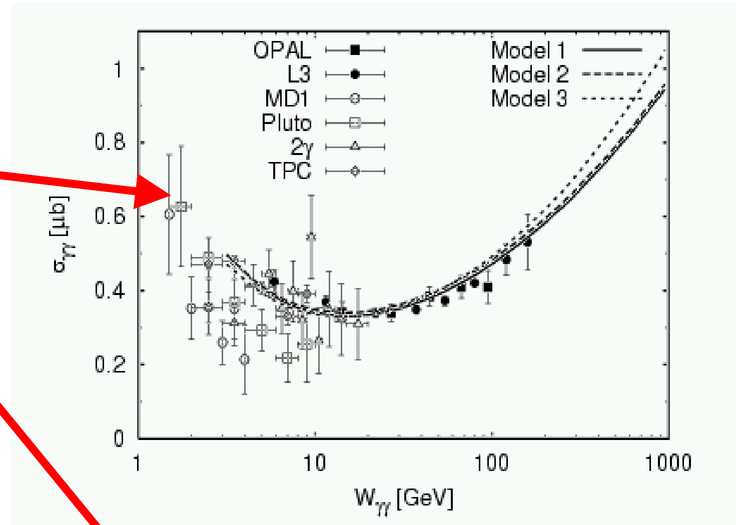


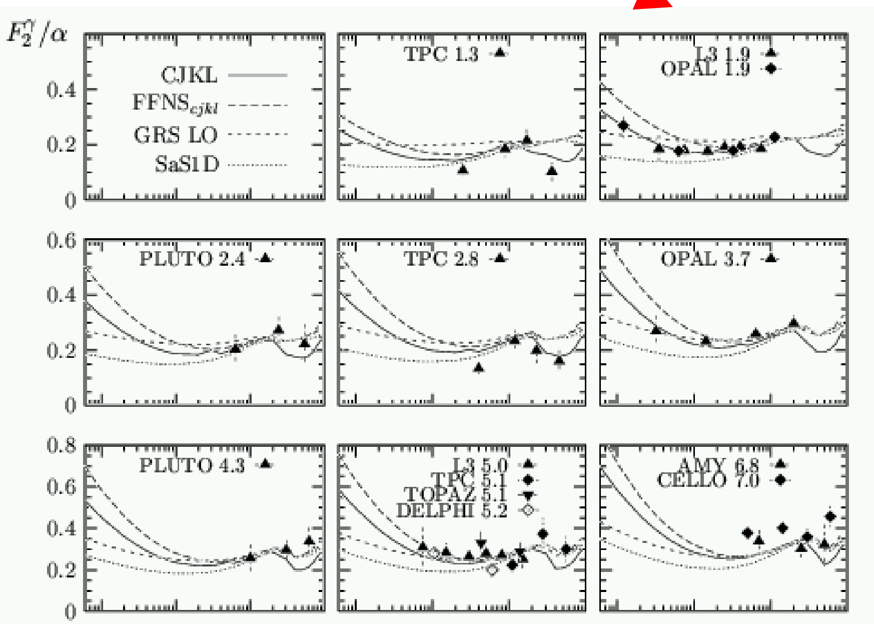
Study beam related background:
e+e- pairs, overlap events, neutrons

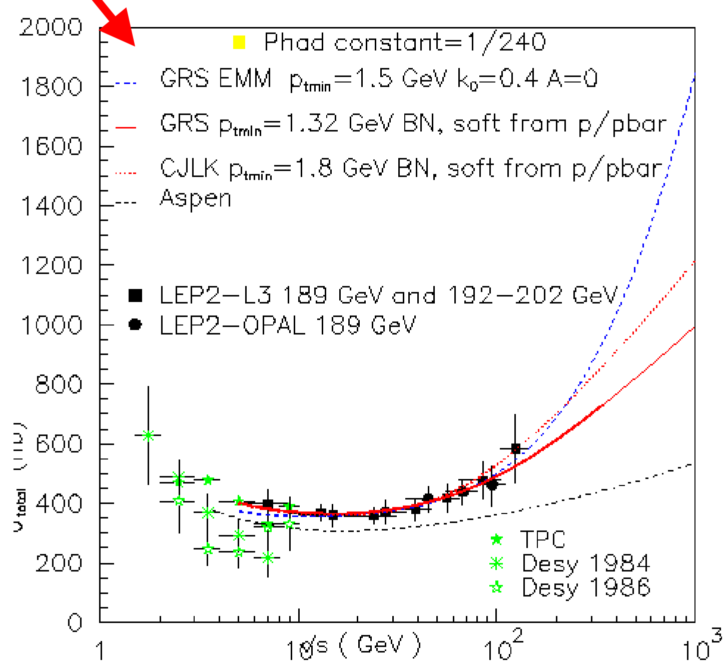
- # of QCD events overlapping now under control (1 evt@ 200 GeV and 2.5 evts @500 GeV). All groups agree (D. Asner, ADR, Telnov, Warsaw)
- # of hits in the layers of the pixel detector per bunch crossing
- Incoherent pair production: essentially the same as for e+e-
- Coherent pair production: High! but ok, similar to e+e-
  $\Rightarrow$ same vertex detector as for e+e-
  (Moenig,Sekaric)
- Neutrons? Probably ok (V. Telnov)

QCD

- Total $\gamma\gamma$ cross section parametrizations
  (Kwiecinski, Motyka,Timneanu) &
  (Pancheri, Grau, Godbole, ADR)
- Structure functions PDFs and Charm treatement
  (Krawczyk et al.)

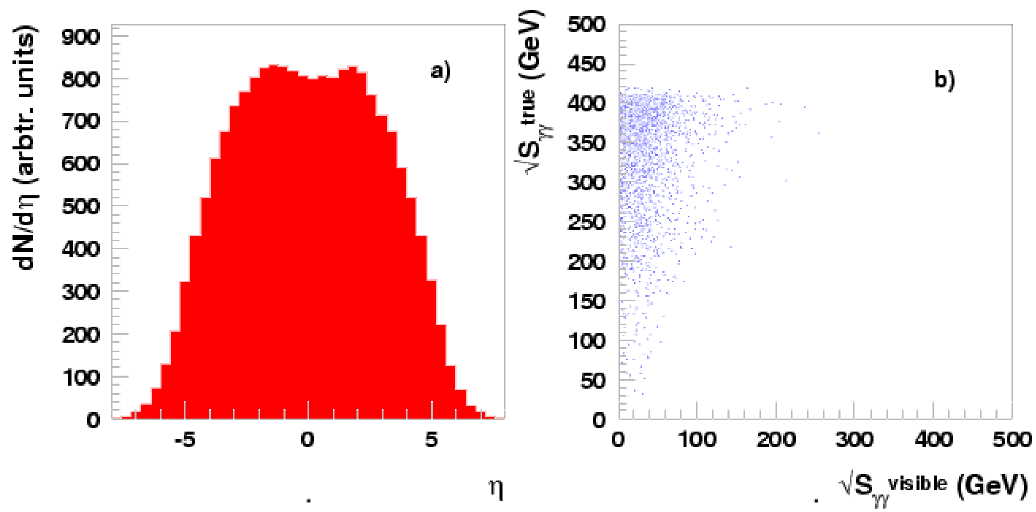


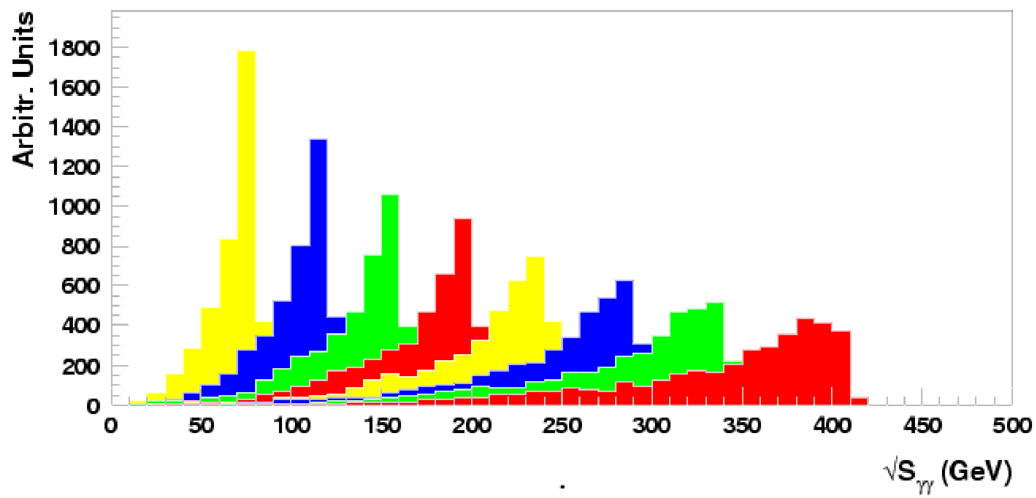




To be used in the Monte Carlo programs

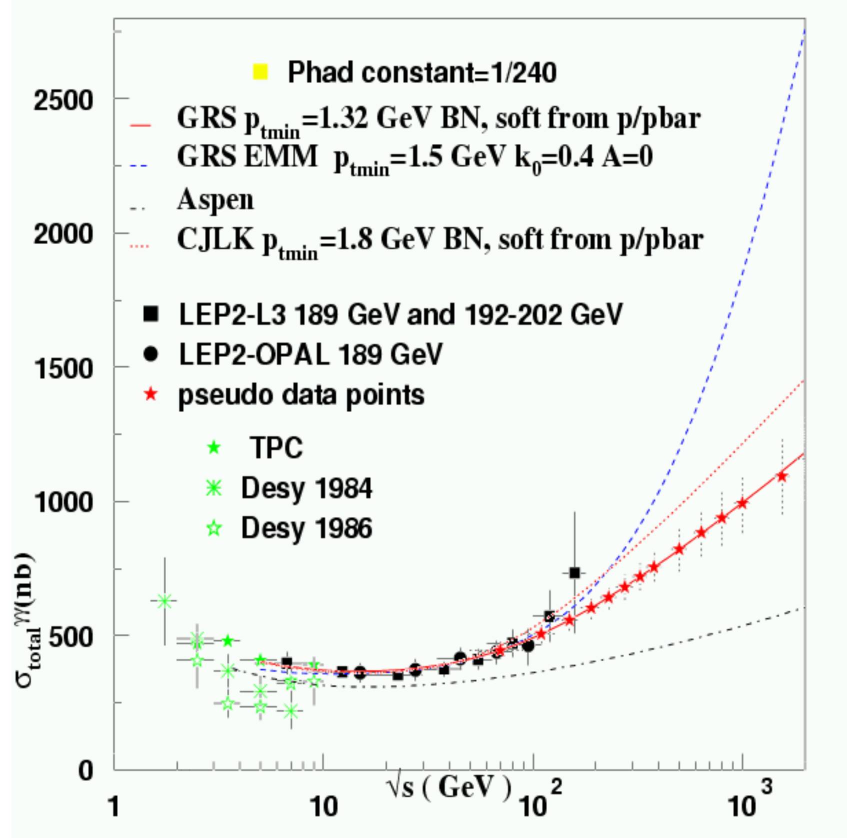
Total Cross Section





Fixed $x = 4.8 \longrightarrow$ change laser energy

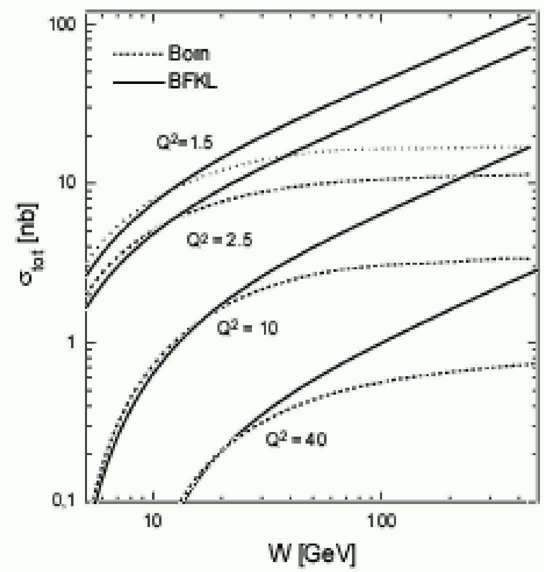
Pancheri, Grau, Godbole, ADR



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

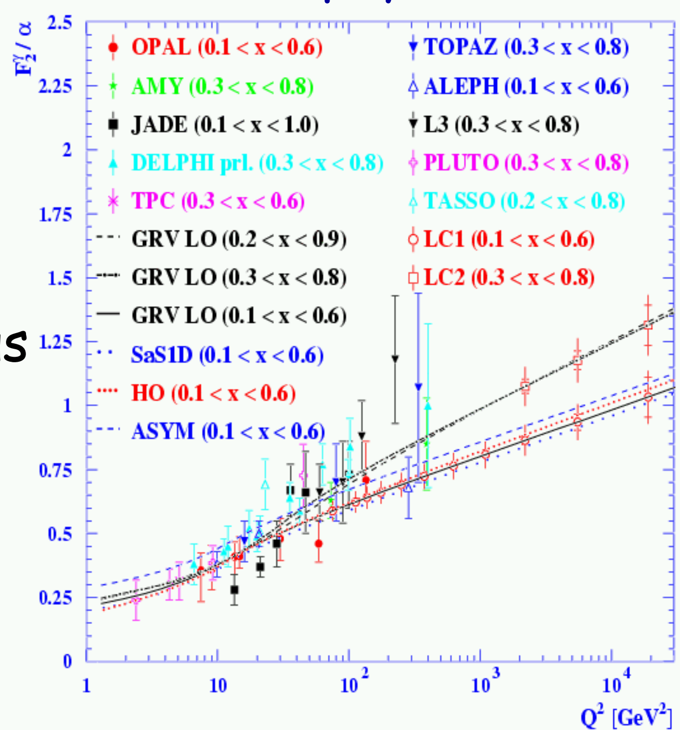
e+e- collider

- 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



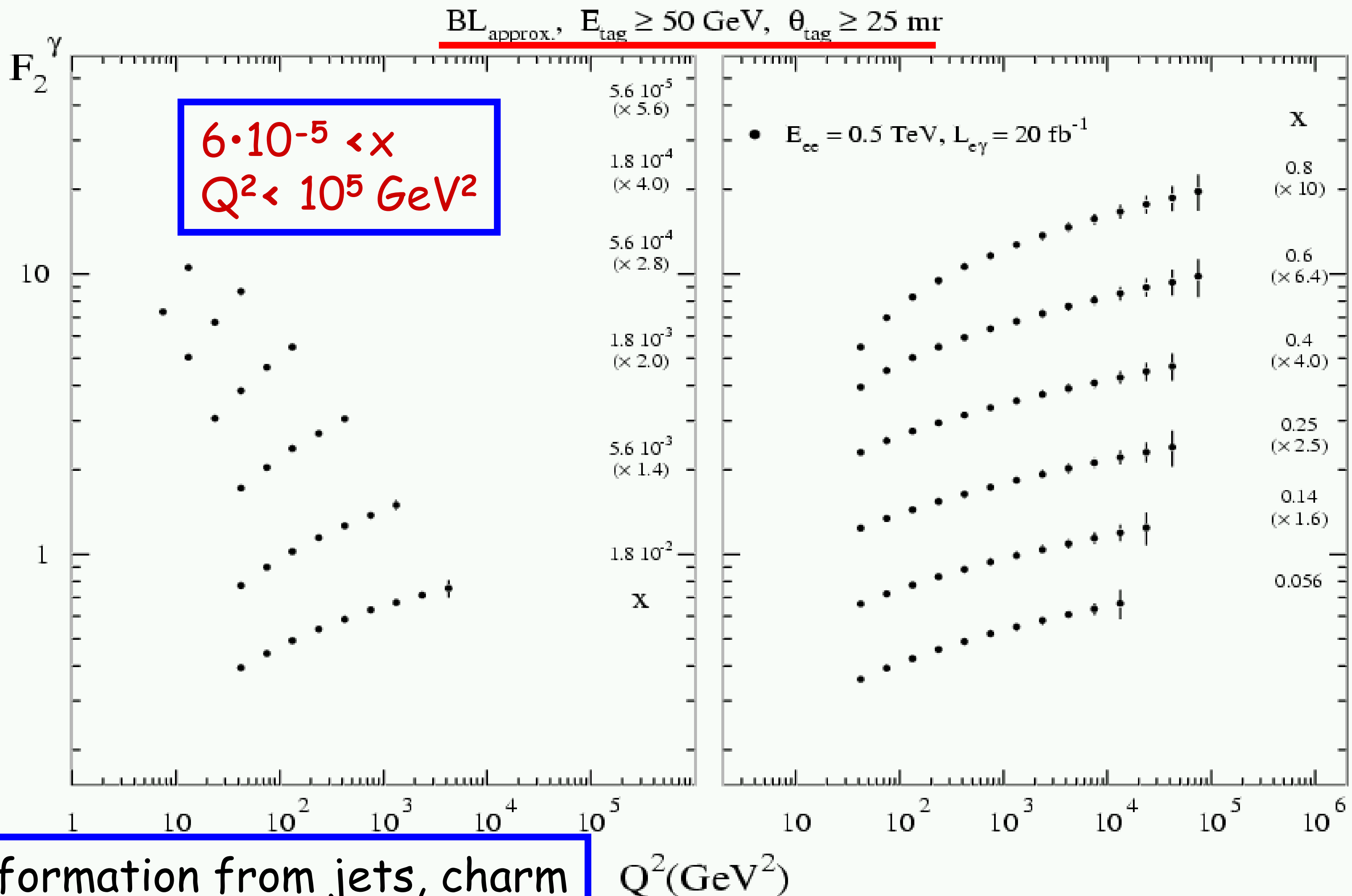
$\theta_{min} - \theta_{max}$	$\sigma(e^+e^- \to e^+e^- + hadrons)$ [fb] Born	Hard	Full (LS)	Events / year Full (LS)
10–20	134	365	450	90000
20–30	16	41	46	9200
30–40	3.5	8	9	1800
40–50	1.1	2.3	2.5	500
50–70	0.6	1.1	1.3	260
30–70	5.2	11	13	2600

QCD

Photon structure function reach at a photon collider

Vogt & ADR

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



Also information from jets, charm

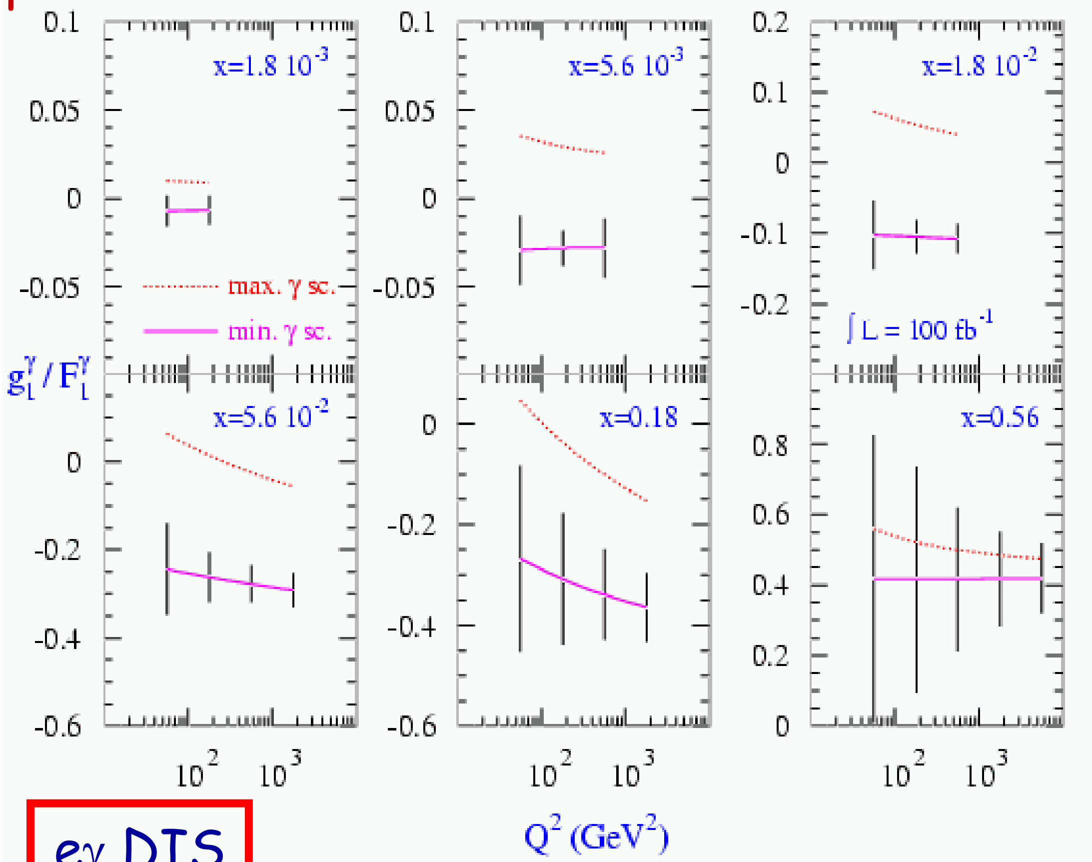
QCD

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

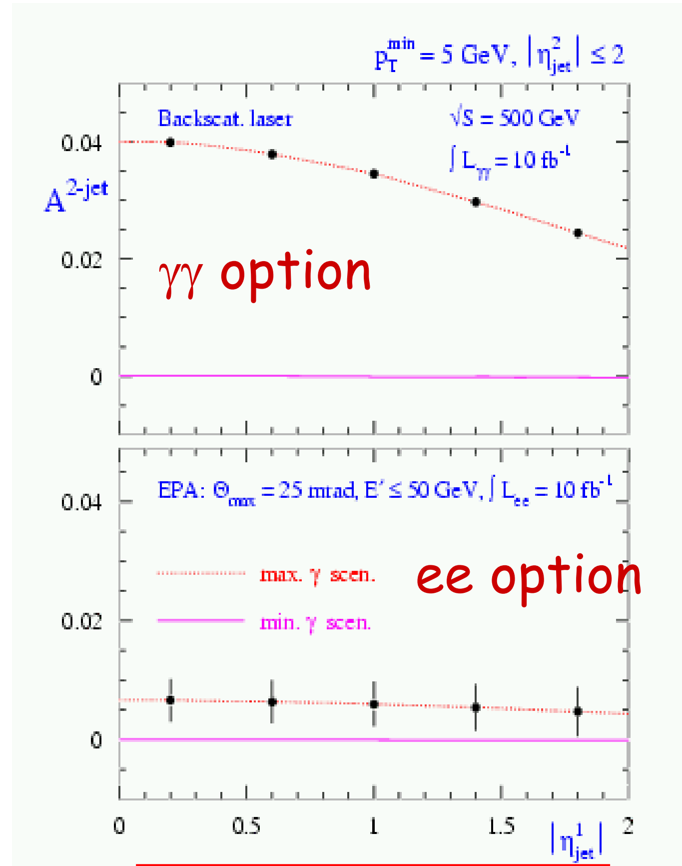
Stratmann and Vogelsang

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

eγ option



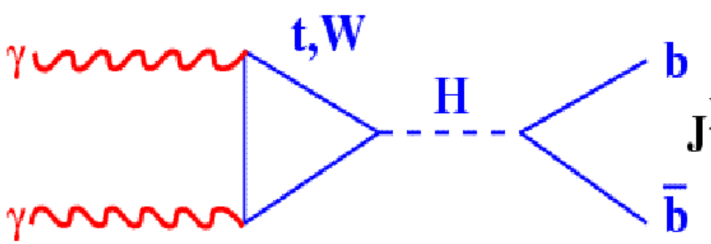
eγ DIS



Jet asymmetries

Higgs

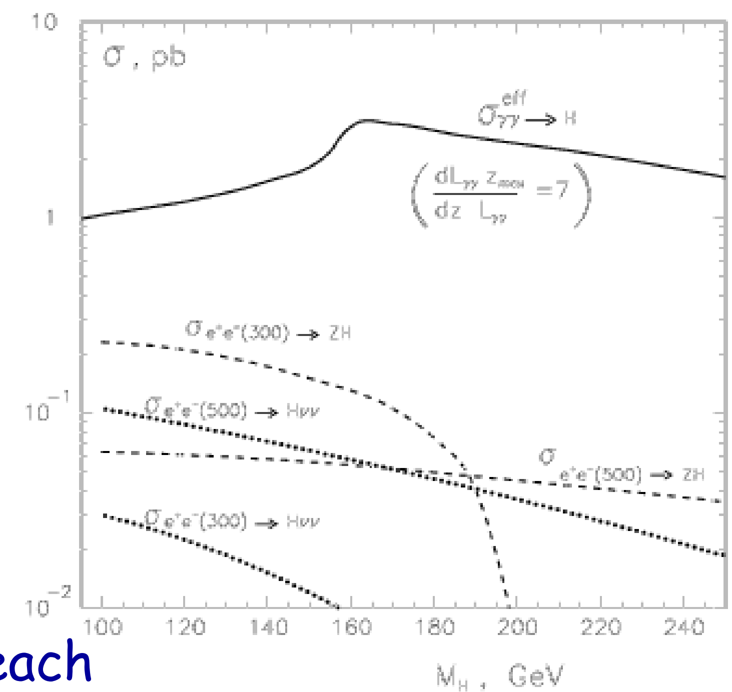
Production Mechanism for Neutral Higgs Bosons



Landau-Yang

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

Heralded as THE key measurement for the gamma-gamma option

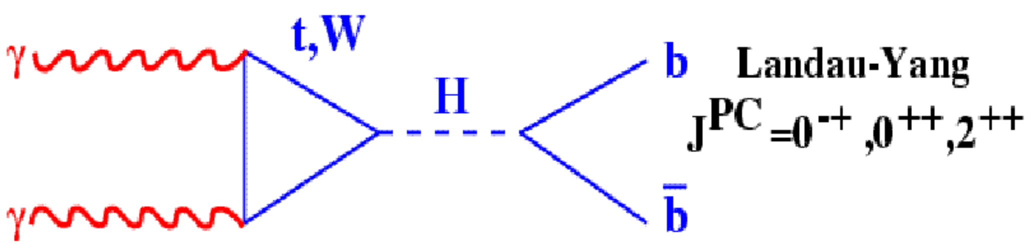


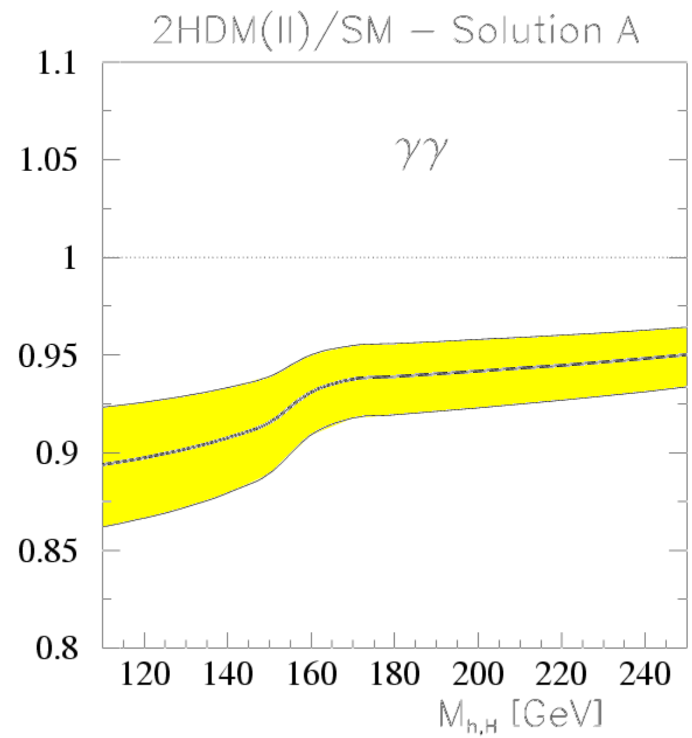
- This ECFA-DESY workshop
  - Study H→ bb, with realistic spectra, background, B-tagging efficiency,…
  - Study H→ WW,ZZ
  - Study model separation power
  - Study spin of Higgs in H→ WW,ZZ
  - Study CP properties of the Higgs
  - Study MSSM Higgs (H,A): extend e+e- reach
  - Study of the charged Higgs (US)

250 350

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





QCD bb in $\gamma\gamma$ suppression: V. Khoze,...

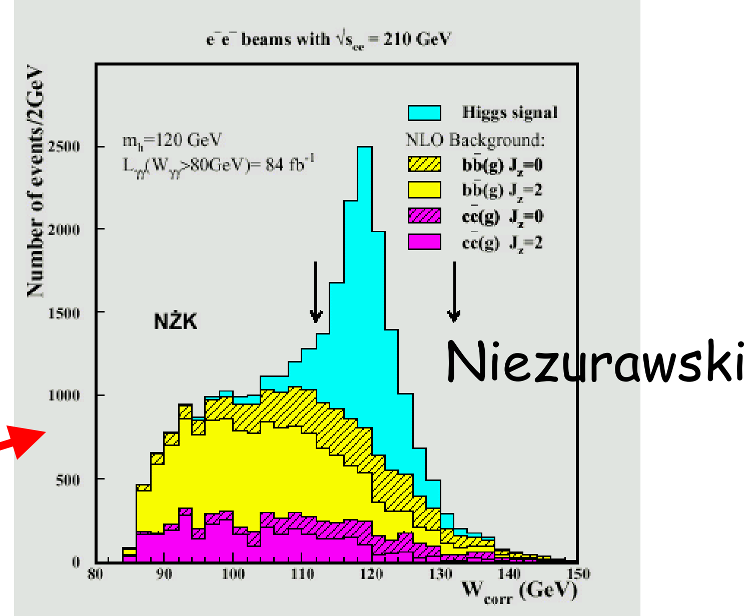
Measure $\Gamma(h \to \gamma\gamma) = \dfrac{[\Gamma(h \to \gamma\gamma)\mathrm{BR}(h \to b\bar{b})]}{[\mathrm{BR}(h \to b\bar{b})]}$

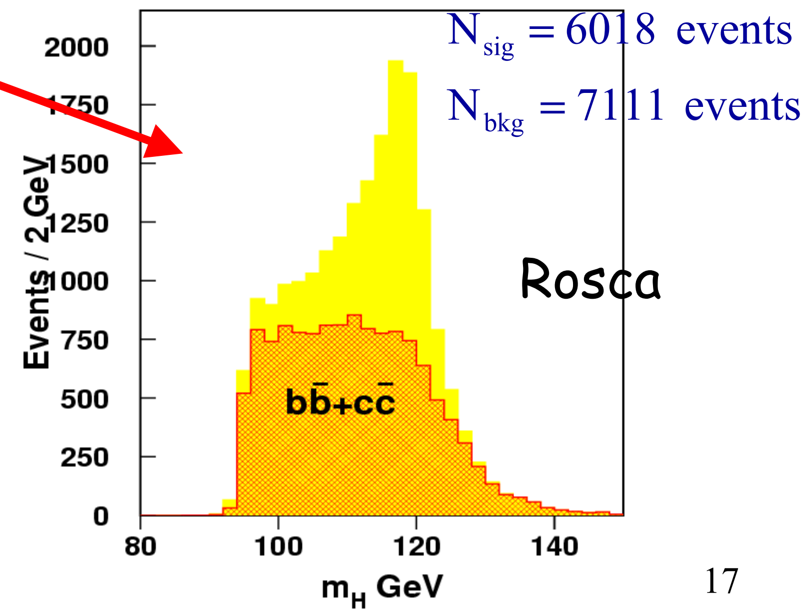
Note: BR(h$\to$bb) measured to 1-2%

Example:
2HDM SM-like versus SM
(Ginzburg, Krawczyk, Osland)

SM Higgs Analysis

- New detailed analyses for Light SM Higgs
  - Realistic photon spectra
  - NLO QCD backgrounds (Jikia)
  - B-tagging via ZVTOP
  - Mass corrected for neutrinos
  - Overlap events (~1 per B.C.)
- 2 independent analyses





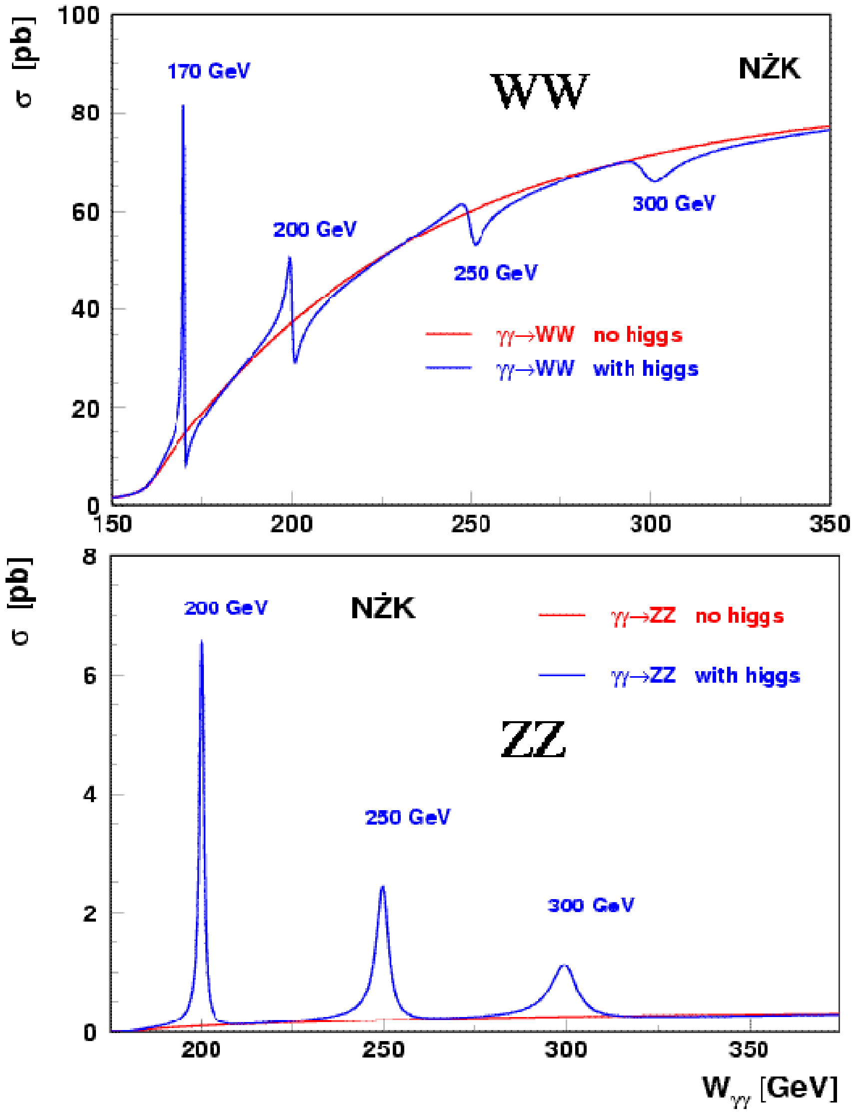
$$\frac{\Delta[\Gamma(h\to\gamma\gamma)\mathrm{BR}(h\to b\bar{b})]}{[\Gamma(h\to\gamma\gamma)\mathrm{BR}(h\to b\bar{b})]} \approx 1.6\text{-}1.9\%$$

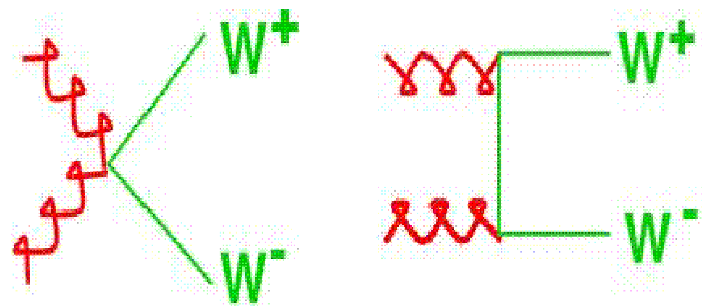
m_h (GeV)	120	130	140	150	160
$\frac{\Delta\sigma}{\sigma}$ (%)	1.8	1.9	2.2	3.0	6.8

SM Higgs

Higgs Decaying into WW or ZZ

A. Zarnecki





Large background from WW production:

interference must be taken into account

<u>additional observable:</u>

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

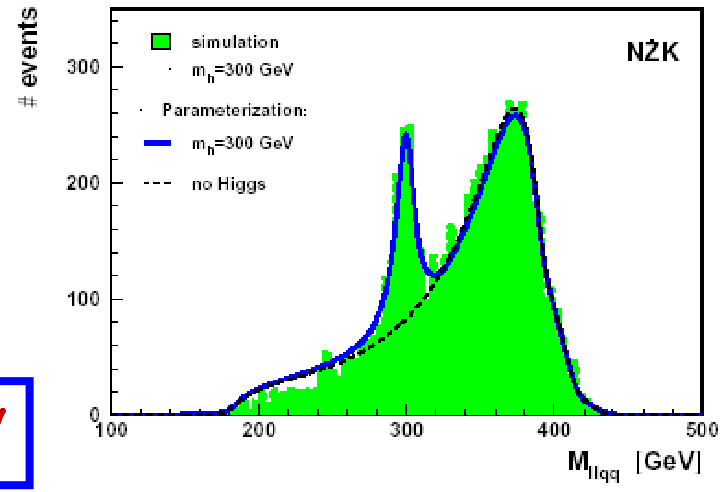
SM Higgs: H→WW,ZZ

A. Zarnecki

Simultaneous determination of the Higgs Boson width and phase
H→ WW and H→ ZZ measurements
(full detector simulation, interference…)

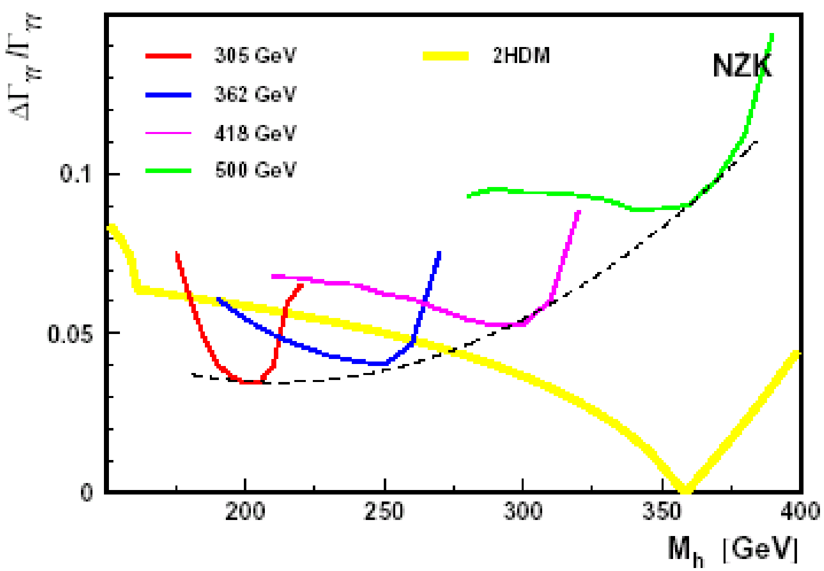
➡ $\Delta\Gamma_{\gamma\gamma}/\Gamma_{\gamma\gamma}$ = 3-10% M_H< 350 GeV

ZZ

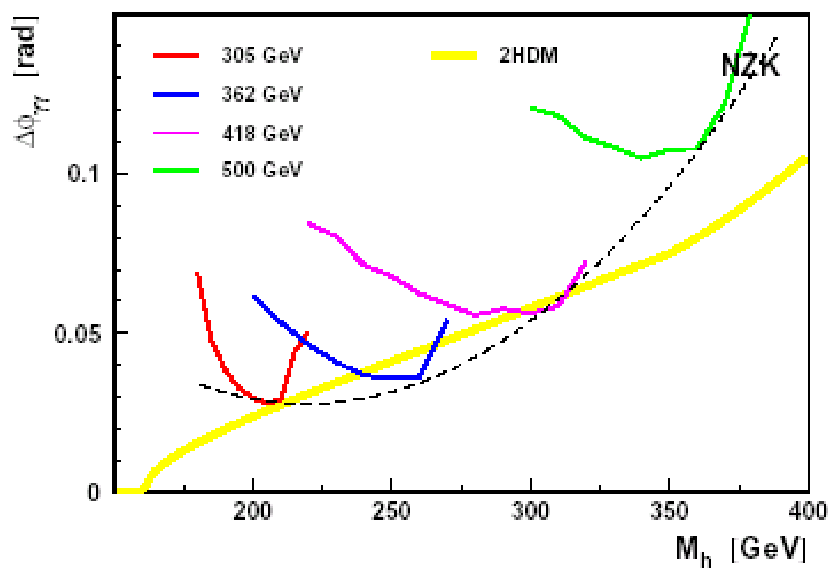


hep-ph/0207294

$\Gamma_{\gamma\gamma}$

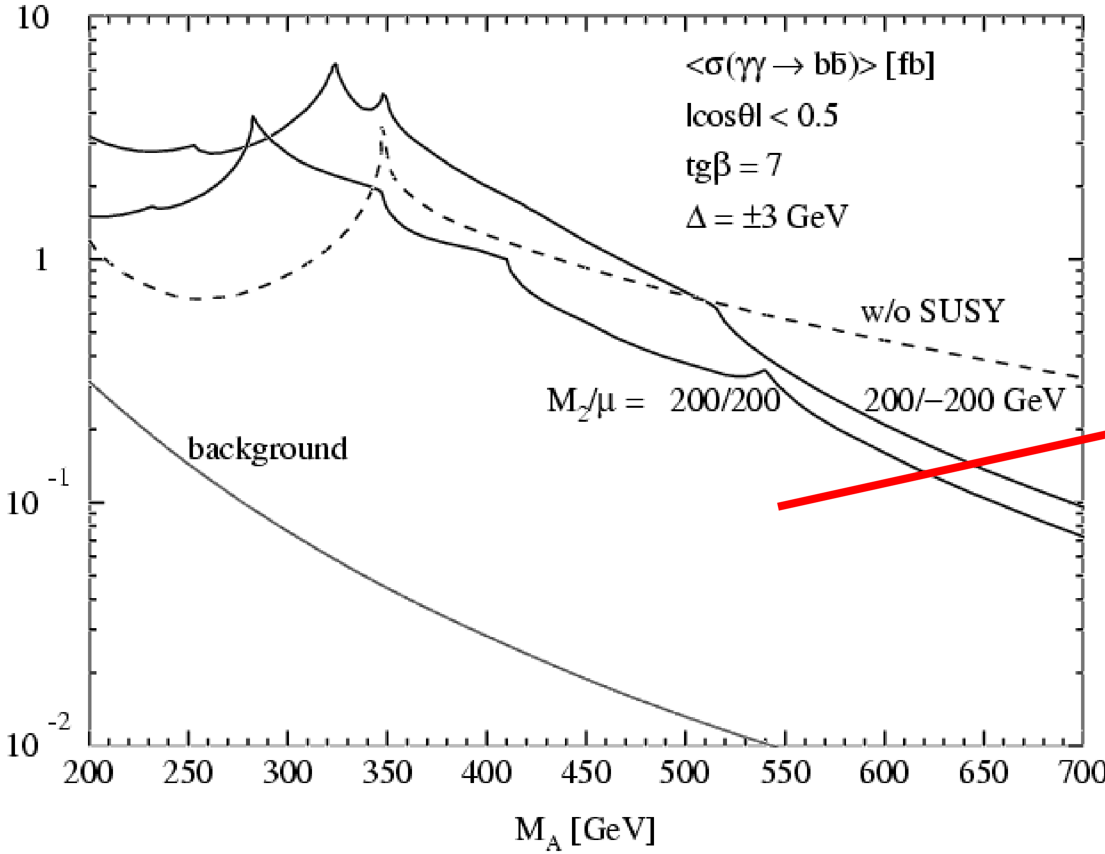


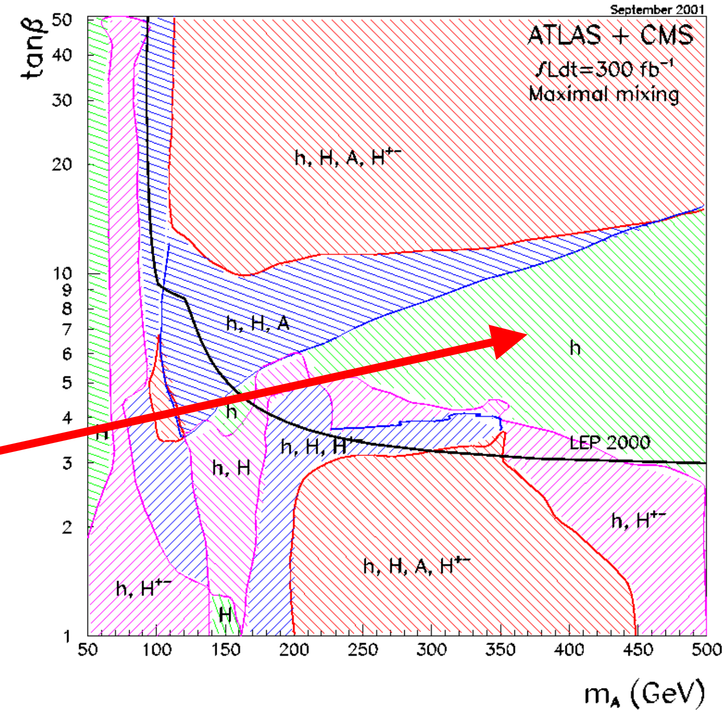
$\phi_{\gamma\gamma}$



MSSM Higgs: H,A

Muhlleitner, Kramer, Spira, Zerwas

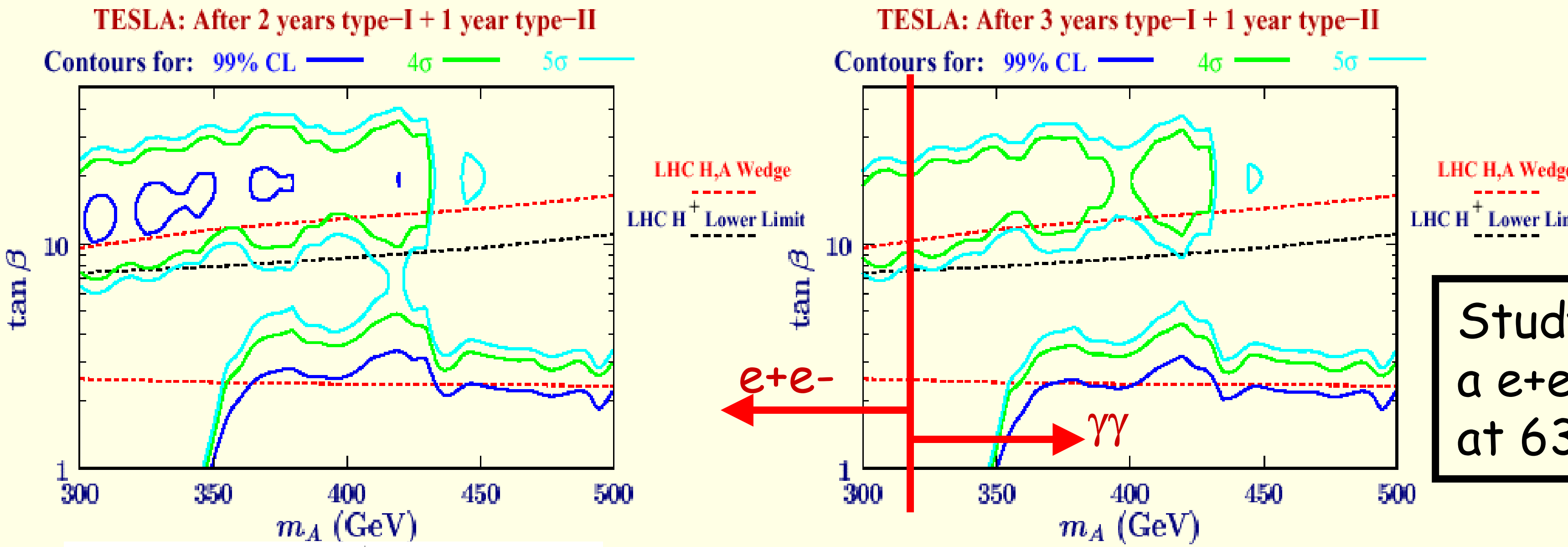




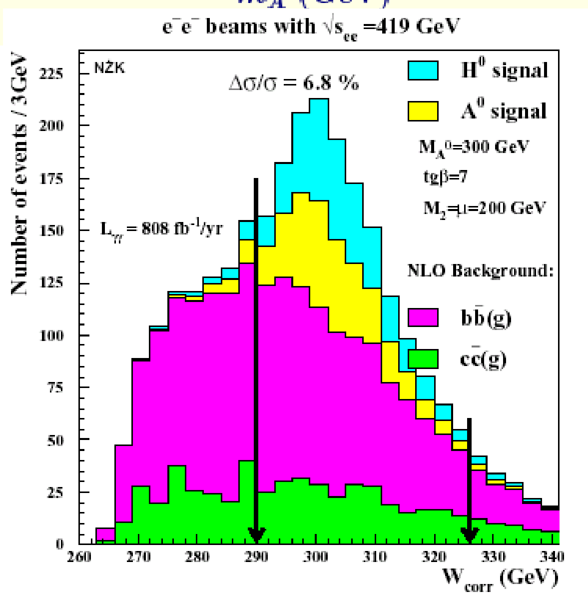
Can a photon collider
Close the LHC wedge?

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

MSSM H/A Higgs



Study for
a e+e- collider
at 630 GeV



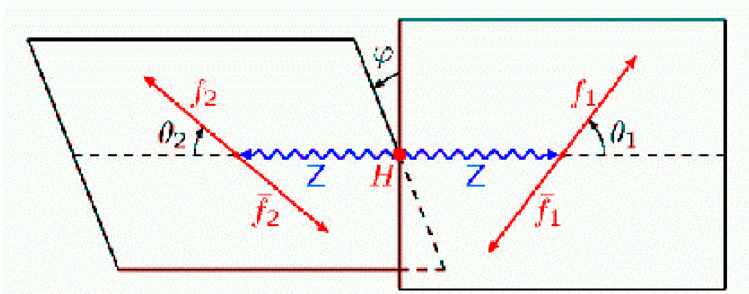
US study D.Asner/J.Gunion (LCWS02)

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

European study in progress P. Niezurawski

- A^0 detectable for M_A > 300 GeV beyond e+e- reach of a 500 GeV e+e- collider

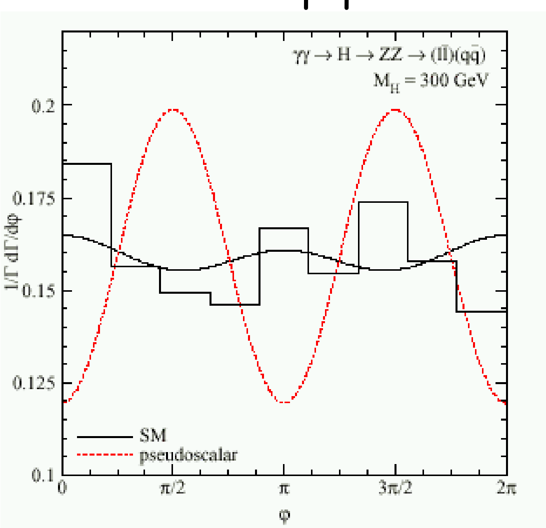
Angular distributions in $\gamma\gamma \to h \to ZZ \to lljj$ and $\gamma\gamma \to h \to WW \to 4j$



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

⇒ Higgs spin and parity

D. Miller et al. hep-ph/0210077



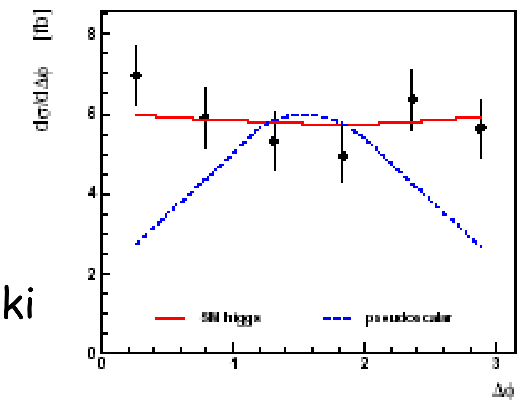
Detector effects are large, but sensitivity left

A. Zarnecki

Realistic simulation

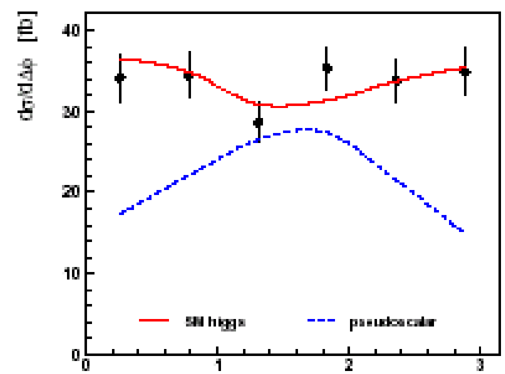
Extracted $\frac{d\sigma}{d\Delta\phi} \times BR(h \to ZZ)$

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



$\Delta\phi$

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

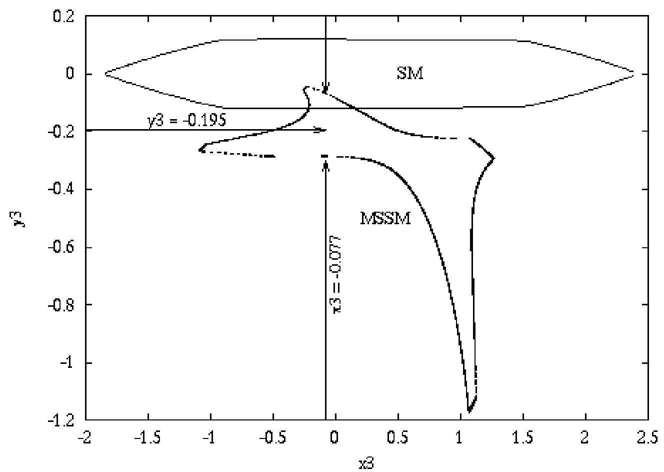
For illustration purposes use a specific MSSM prediction for the form factors of the scalar (Askawa et al):

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

Choose the MSSM point given above, calculate x_i, y_j for that choice of CP violating parameters.

Find regions in the x_i, y_j planes around this point outside which measurements of asymmetries can test the hypothesis of this being the correct model.

Do the same for the SM meaning $x_i, y_j = 0$ in our parametrisation.



The asymmetries have sensitivity to loop induced CP violation in the Higgs sector of the MSSM

R. Godbole et al.
hep-ph/021136 & LCWS02

Exciting possibility to analyse CP structure of the scalar

Construct combined asymmetries from intial lepton polarization and decay lepton charge

Done with Compton spectra
Using COMPAZ reduces sensitivity with factor 2

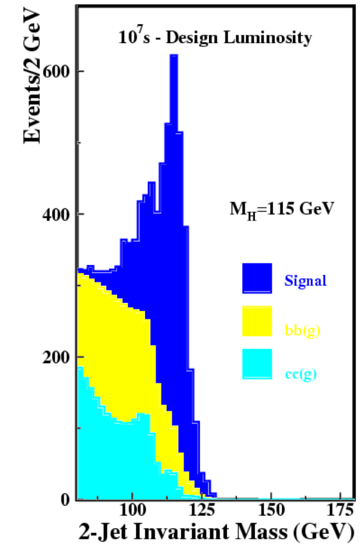
Needs detector simulation

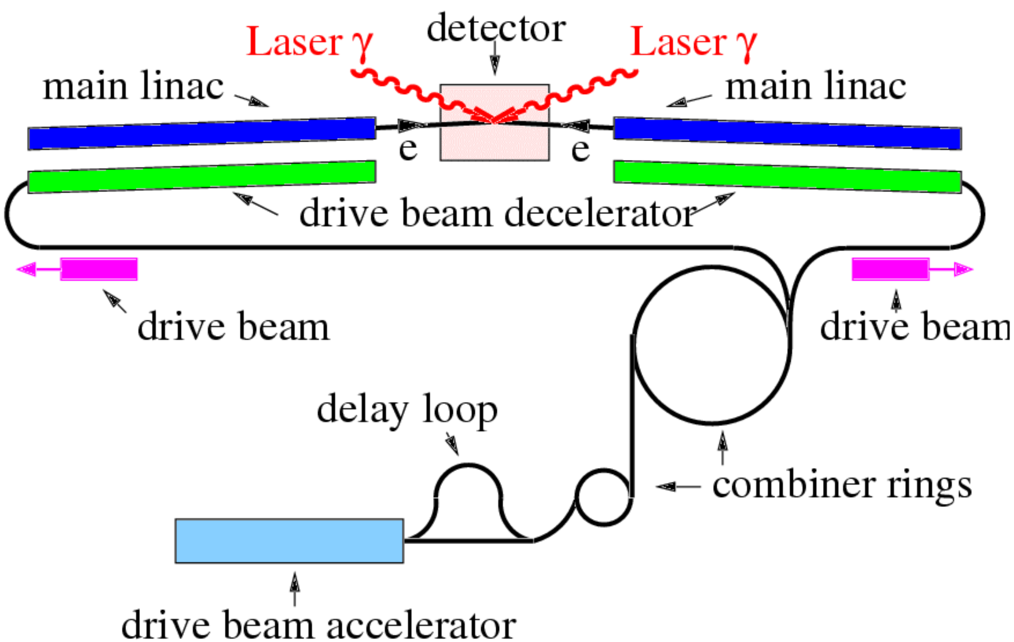
CLICHE

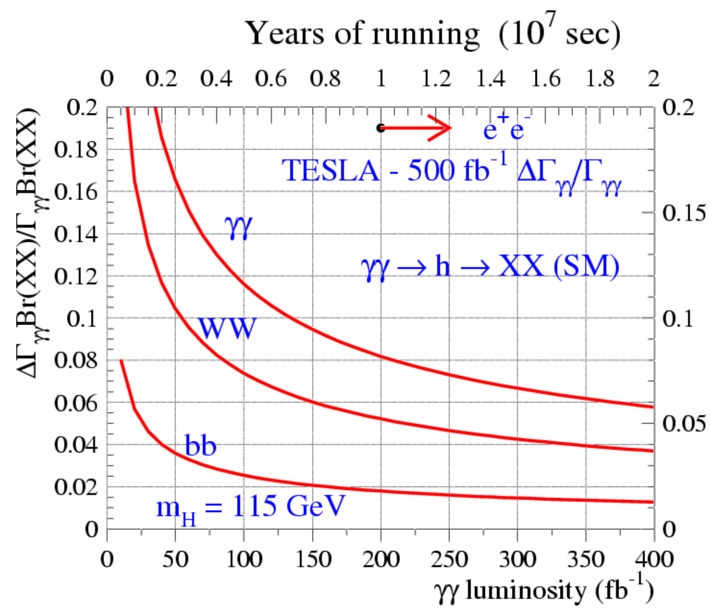
D. Asner et al., hep-ex/0111056

CLICHÉ: CLIC Higgs Experiment

- Possible demonstration project for CLIC after CTF3 (ends 2007-2008)
- Uses only 2 CLIC modules (5%)
- Measure Higgs & more





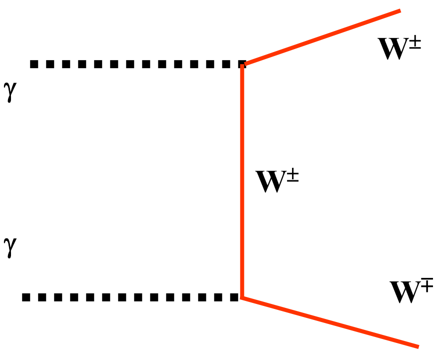


Triple Gauge Couplings

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

Sekaric, Moenig
Bosovic, Anipko

Measure precisly the gauge couplings



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

$e\gamma$ gives good Sensitivity
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)	$-0.008 \div +0.008$	$-0.016 \div +0.016$

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

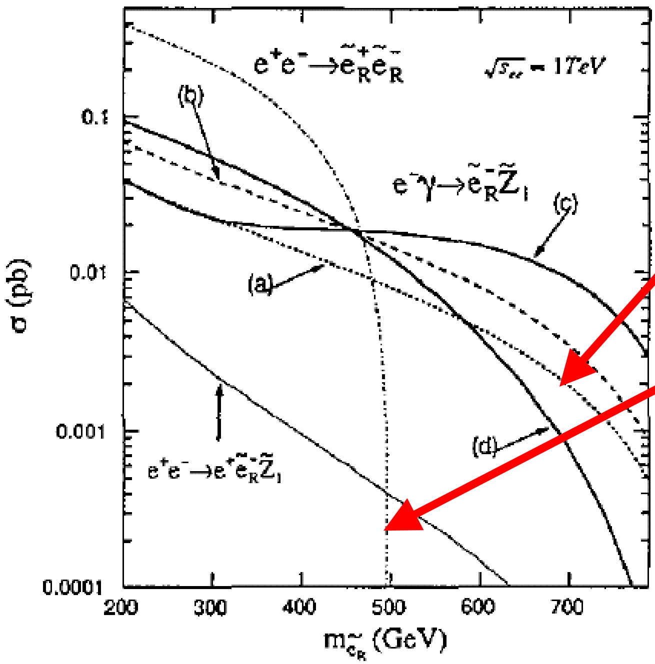
Beam energy: 250 GeV. L=20 fb^{-1}. Cut-off angle 30 deg.

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

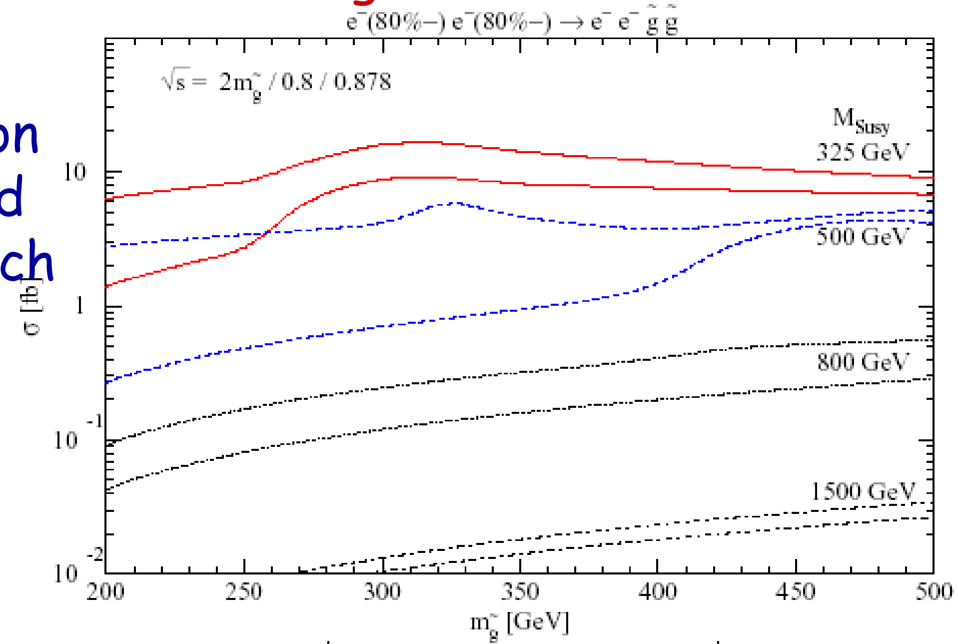
$$e^-\gamma \rightarrow \tilde{e}_{L,R}\chi_1^{(0)} \rightarrow e^-\chi^{(0)}\chi^{(0)}$$



Light LSP & heavy Slepton $\gamma\gamma$ can extend the e+e- reach

Kraus, Wengler

New also $\gamma\gamma \rightarrow$gluinos
Cannot be done at e+e- ($m_g > m_q$)
Interesting but needs simulation



F.S.	Compton	+ ISR	CompAZ	+ ISR
eZ	4.26 pb	4.34 pb	3.07 pb	3.11 pb
$\nu_e W$	11.56 pb	11.31 pb	6.71 pb	6.66 pb
$\tilde{e}_R\chi_1^{(0)}$	155.3 fb	151.4 fb	90.5 fb	88.6 fb
$\tilde{e}_L\chi_1^{(0)}$	15.38 fb	14.71 fb	9.08 fb	8.70 fb

- $E_{ee} = 2m_{\tilde{g}}/.8/.878$:
  - 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

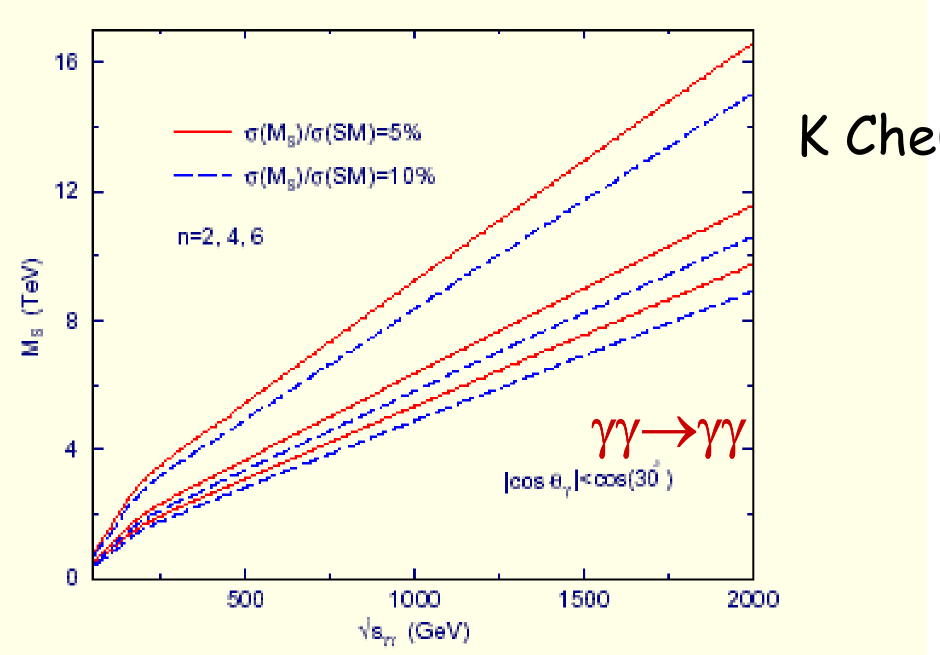
Klasen, Berge

Extra Dimensions

Extra space dimensions

ADD: Planck scale in TeV range

Photon collider has a large sensitivity



K Cheung

T.Rizzo

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
$\gamma\gamma \to \ell^+\ell^-/t\bar{t}/jj$	$4\sqrt{s}$
$\gamma\gamma \to \gamma\gamma/ZZ$	$4-5\sqrt{s}$
$\gamma\gamma \to W^+W^-$	$11\sqrt{s}$

Also Radion search:
J. Gunion et al.

Extra Dimensions

ADD type extra dimensions
Sensitivity to mass M_s

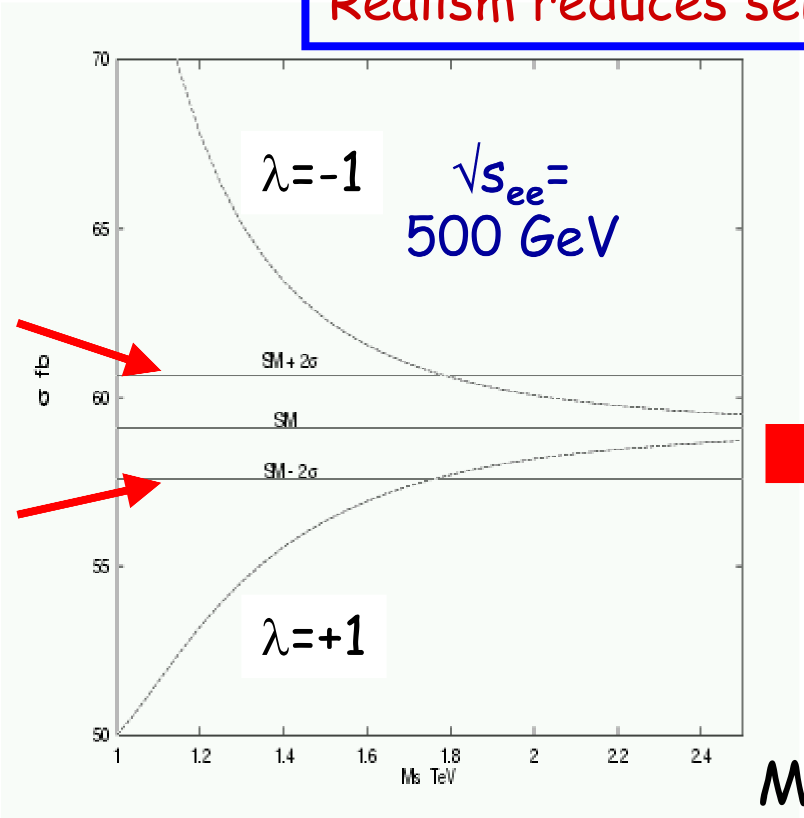
P. Poulose

$\gamma\gamma \rightarrow tt$

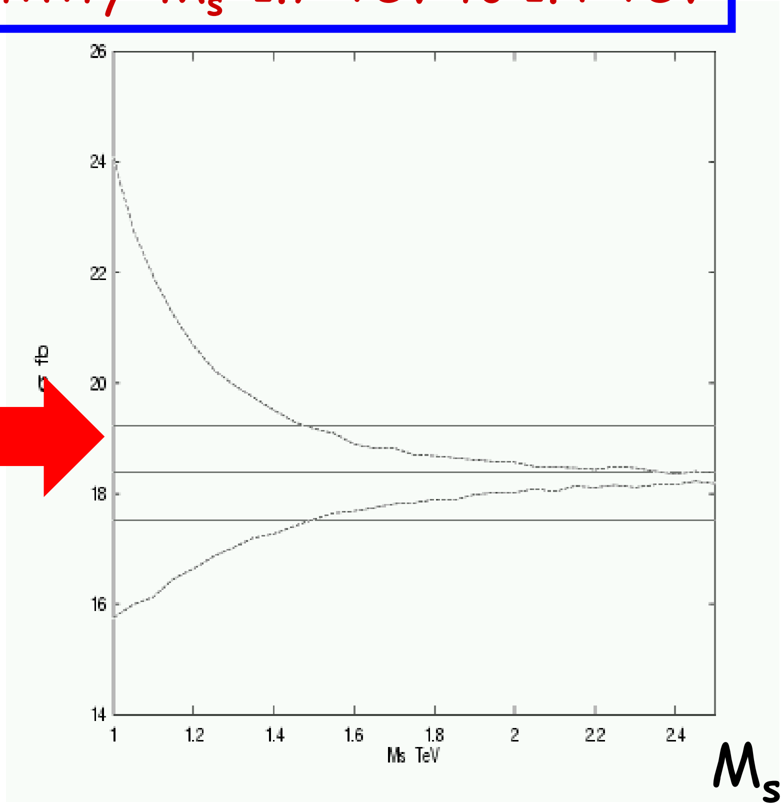
Realism reduces sensitivity: M_s=1.7 TeV to 1.4 TeV

SM+2σ

SM-2σ



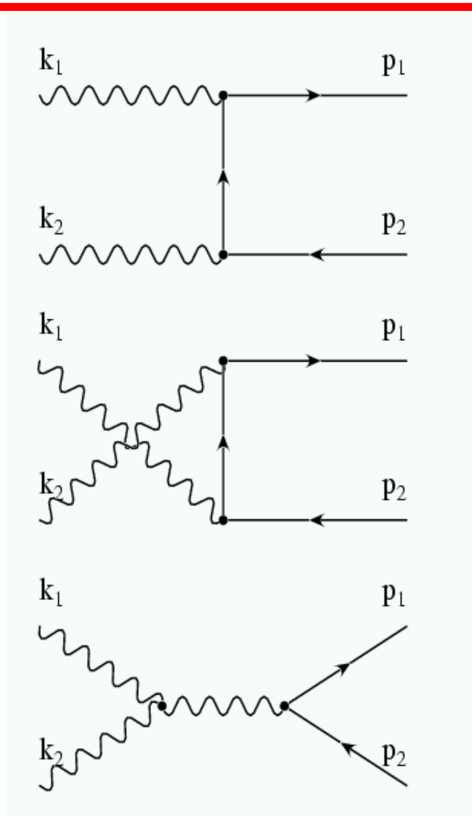
Ideal Compton spectrum



COMPAZ spectrum

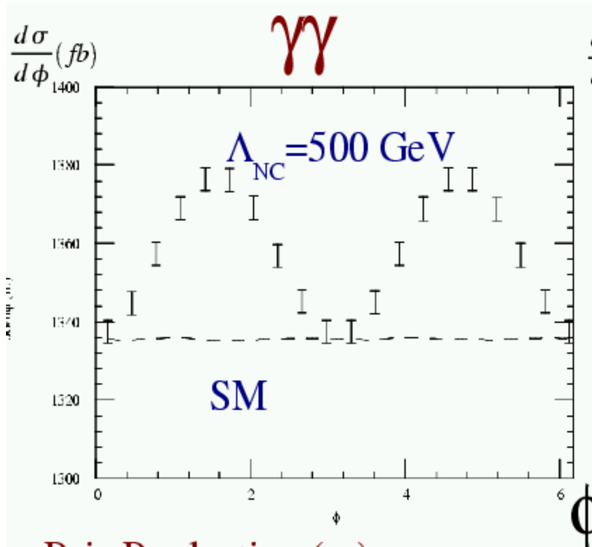
Non-commutative theories

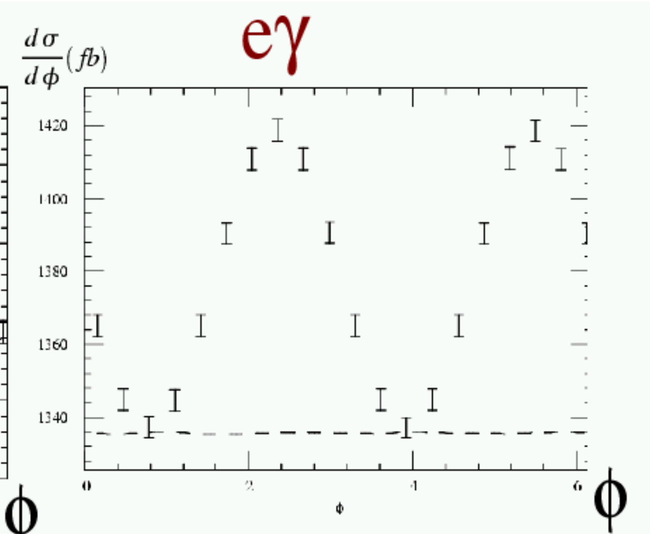
Breakdown in QED due to prefered direction in space: azimuthal effects



this study:

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





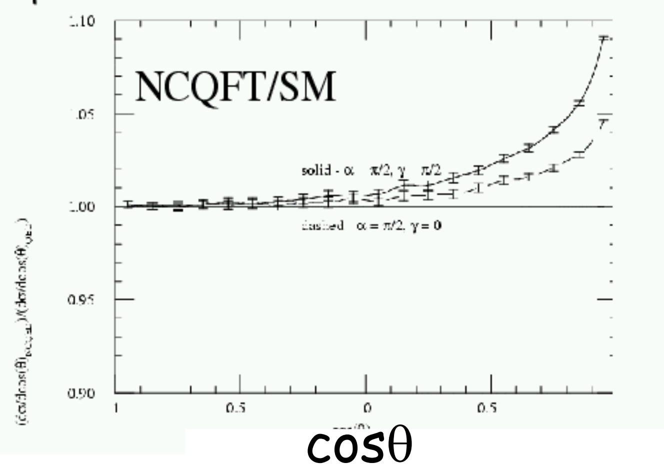
Pair-Production (γγ):

-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



Golden Processes

hep-ph/0103090

	Reaction	Remarks	
✪	$\gamma\gamma \to h^0 \to b\bar{b}$	$\mathcal{SM}$ or $\mathcal{MSSM}$ Higgs, $M_{h^0} < 160$ GeV	Higgs
✪	$\gamma\gamma \to h^0 \to WW(WW^*)$	$\mathcal{SM}$ Higgs, $140\,\text{GeV} < M_{h^0} < 190$ GeV	
✪	$\gamma\gamma \to h^0 \to ZZ(ZZ^*)$	$\mathcal{SM}$ Higgs, $180\,\text{GeV} < M_{h^0} < 350$ GeV	
✪	$\gamma\gamma \to H, A \to b\bar{b}$	$\mathcal{MSSM}$ heavy Higgs, for intermediate $\tan\beta$	SUSY
★	$\gamma\gamma \to \tilde{f}\bar{\tilde{f}},\ \tilde{\chi}_i^+\tilde{\chi}_i^-,\ H^+H^-$	large cross sections, possible observations of FCNC	
	$\gamma\gamma \to S[\tilde{t}\bar{\tilde{t}}]$	$\tilde{t}\bar{\tilde{t}}$ stoponium	
✪	$\gamma e \to \tilde{e}^-\tilde{\chi}_1^0$	$M_{\tilde{e}^-} < 0.9 \times 2E_0 - M_{\tilde{\chi}_1^0}$	
✪	$\gamma\gamma \to W^+W^-$	anomalous W interactions, extra dimensions	Tril/quart.
✪	$\gamma e^- \to W^-\nu_e$	anomalous W couplings	
★	$\gamma\gamma \to WWWW, WWZZ$	strong WW scatt., quartic anomalous W, Z couplings	
★	$\gamma\gamma \to t\bar{t}$	anomalous top quark interactions	Top
	$\gamma e^- \to \bar{t}b\nu_e$	anomalous Wtb coupling	
✪	$\gamma\gamma \to$ hadrons	total $\gamma\gamma$ cross section	QCD
✪	$\gamma e^- \to e^-X$ and $\nu_e X$	$\mathcal{NC}$ and $\mathcal{CC}$ structure functions (polarized and unpolarized)	
✪	$\gamma g \to q\bar{q},\ c\bar{c}$	gluon distribution in the photon	
✪	$\gamma\gamma \to J/\psi\, J/\psi$	QCD Pomeron	

✪ Being done or ready: should be ready for the writeup

★ promised

Golden Processes

Added at/since the start of the workshop 14/9/01:

- Non-commutative QED
- $e\gamma$ for ED's
- Light gravitinos
- Radions
- Gluino production
- $H \to \gamma\gamma$ (US groups)
- $H \to H^+H^-$ (US groups)
- CP analyses in the Higgs sector

More (as yet uncovered/lower priority at present)

- $e\gamma \to e^*$
- Leptoquarks
- Strong WW scattering
- $e\gamma \to eH$

As always: still room for volunteers (continuation of workshop)

Conclusions

Many detailed studies on the physics case for the photon collider

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

A photon collider needs second interaction point and R&D (laser…)

Is it worthwile?

Jeju (LCWS2002) panel discusion: ✪ Yes

$\gamma\gamma$/eγ collider confirmed as an exciting option for a LC !