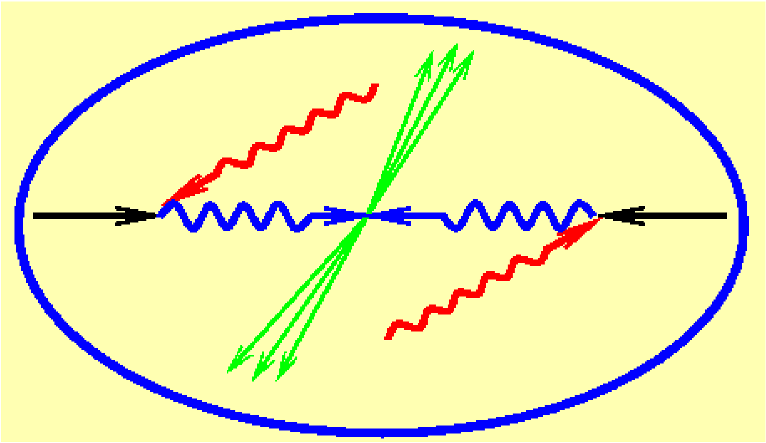

Photon collider at the ILC: first 40 years

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Budker INP and Novosibirsk State Univ.

ILCX-2021, Oct.28

Contents

- Idea of a high energy photon collider based on LC
- Compton scattering, properties of γ-beams, optimum laser wavelength, required flash energy
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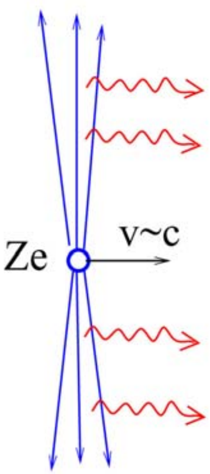
- Removal of disrupted beams, crossing angle, beamdump
- Laser schemes
- Projects of photon colliders (ILC, CLIC), status
- Physics motivation for high energy $\gamma\gamma$ colliders (shortly)
- Conclusion

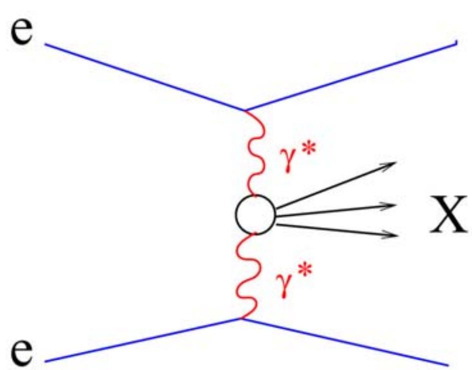
Prehistory: colliding $\gamma^*\gamma^*$ photons

(γ^* -virtual, quasi-real photon)

The idea to study some physics in photon-photon collisions is about 75 years old. The problem: a source of high energy photons.

In 30-th, Fermi-Weizsacker-Williams noticed that the field of a charged particle can be treated as the flux of almost real photons.





Landau-Lifshitz processes

Such two-photon processes have been discovered and studied at all e^+e^- storage rings since 1970th

$$X = e^+e^-, \mu^+\mu^-, \ldots \eta'(960) \ldots, \text{ any C+ resonances}$$

$$m_\gamma \geq m_e/\gamma$$ - almost real

Physics in $\gamma^*\gamma^*$ is quite interesting, though it is difficult to compete with e^+e^- collisions because the number of equivalent photons is rather small and their spectrum soft

$$dn_\gamma \approx \frac{2\alpha}{\pi}\frac{dy}{y}\left(1 - y + \frac{1}{2}y^2\right)\ln\frac{E}{m_e} \sim 0.035\,\frac{d\omega}{\omega};$$

$L_{\gamma\gamma}(z>0.1) \sim 10^{-2}\, L_{e+e-}$

$L_{\gamma\gamma}(z>0.5) \sim 0.4 \cdot 10^{-3}\, L_{e+e-}$

$z = W_{\gamma\gamma}/2E_0$

$\gamma^*\gamma^*$

1970 $e^+e^- \to e^+e^-e^+e^-$ Novosibirsk, VEPP-2

EVIDENCE FOR ELECTRON-POSITRON PAIR ELECTROPRODUCTION

V. E. BALAKIN, A. D. BUKIN, E. V. PAKHTUSOVA, V. A. SIDOROV and A. G. KHABAKHPASHEV
Nuclear Physics Institute, Novosibirsk, USSR

Received 25 February 1971

The process of pair electroproduction has been observed in the electron-positron interaction at the energy 2×510 MeV. The work has been done with the colliding beam machine VEPP-2 in Novosibirsk. The cross section of this process and the azimuth angular distribution for large out-of-flight angles of the produced particles have been measured.

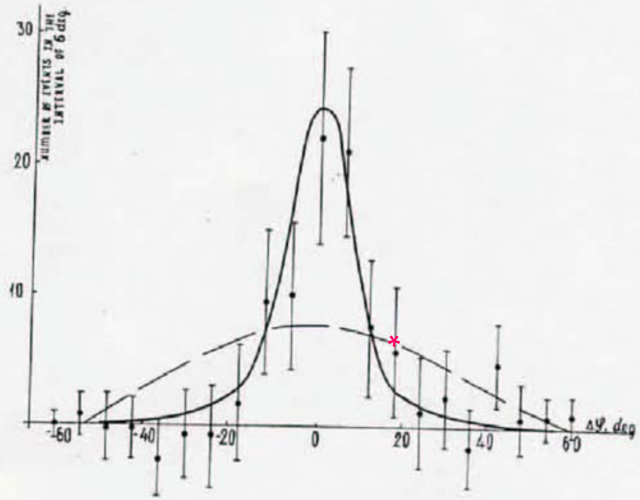


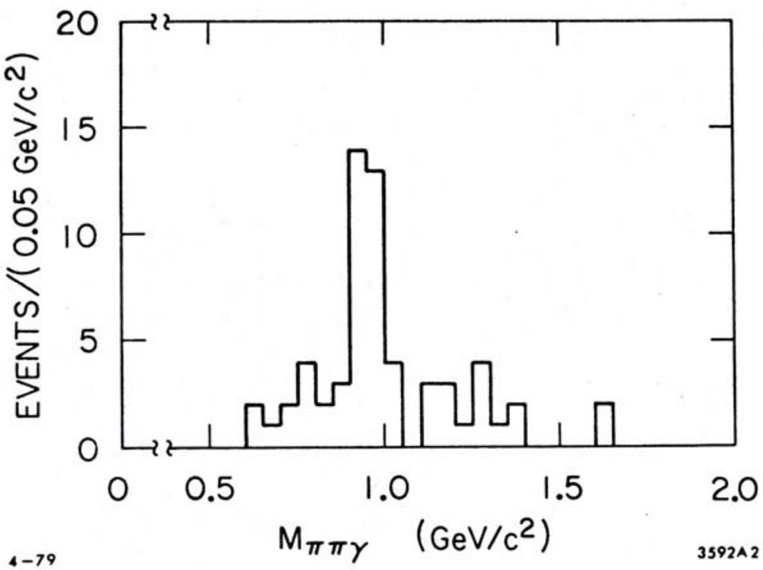
Fig.1. Pair electroproduction events distribution with respect to angle $\Delta\varphi$. Solid curve is obtained with the Baier and Fadin formulas. Dashed one represents the computed distribution for the process with independent and isotropic particle distribution.

In the detector
coplanar e+e- pairs (Δφ~180º)

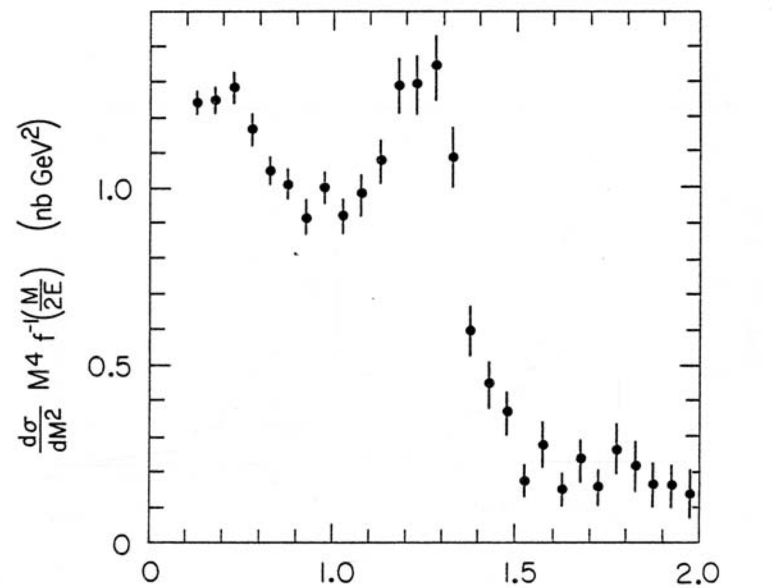
First observation of $\gamma^*\gamma^* \to$ hadron C+ resonances

(V. Telnov, e+e- SPEAR, SLAC, 1979)

$\gamma^*\gamma^* \to \eta'(958) \to \rho\gamma \to \pi^+\pi^-\gamma$



$\gamma^*\gamma^* \to f_2(1270) \to \pi^+\pi^-$



PRL, May 1979

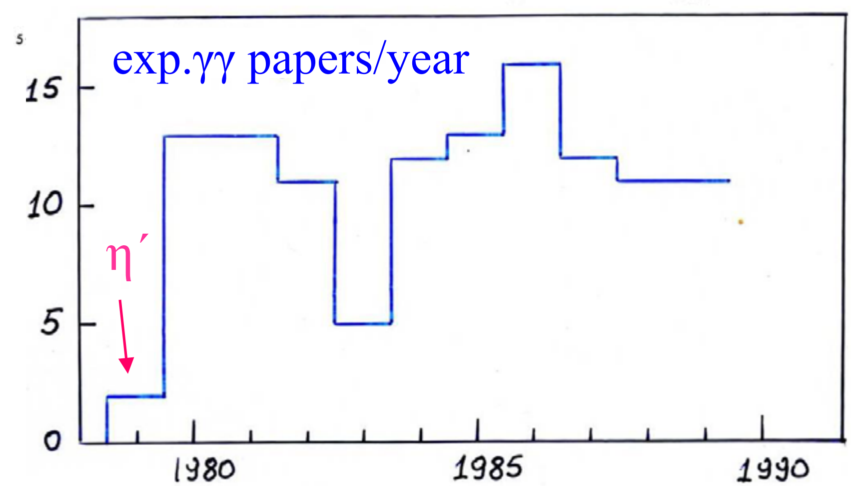
$\Gamma_{\gamma\gamma}(\eta') = 5.9 \pm 1.6 \pm 1.2$ keV

(small statistics, 5.5 pb^{-1})

Theory:

Han-Nambu - 25 кэВ

Gell-Mann - 6 кэВ

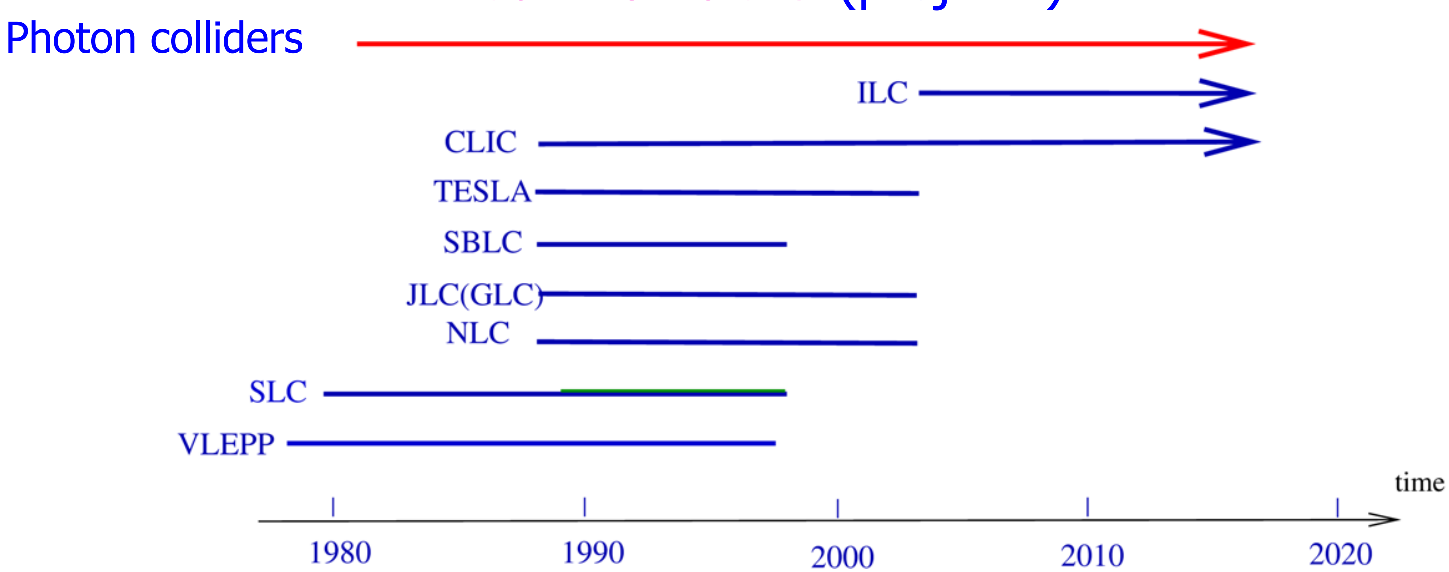


Idea of the photon collider (1981) based on one pass linear colliders

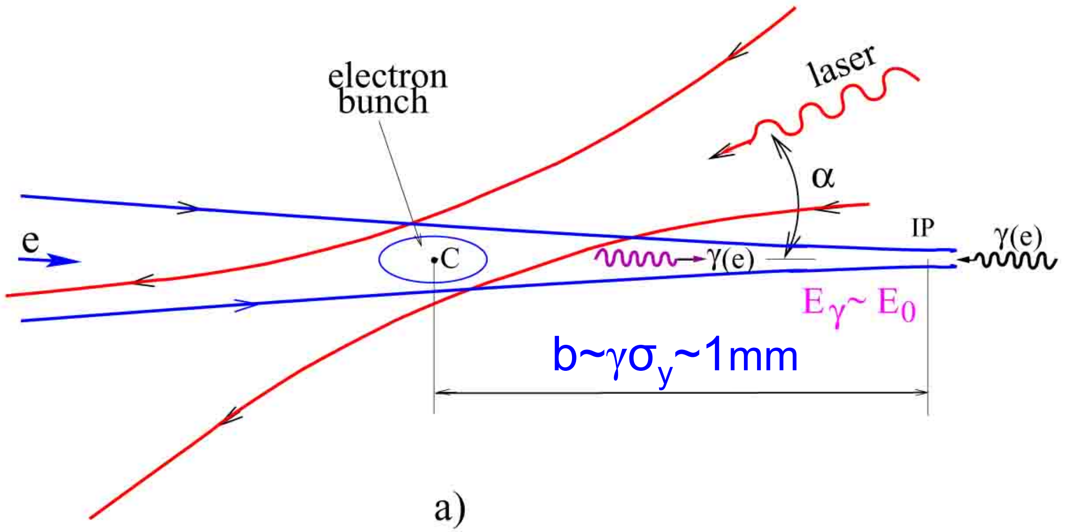
The idea of the high energy photon collider (V.T.) was proposed at the first workshop on physics at linear collider VLEPP (Novosibirsk, Dec. 1980) and is based on the fact that at linear e^+e^- (e^-e^-) colliders electron beams are used only once which makes possible to convert electron beam to high energy photons just before the interaction point.

The best way of $e \to \gamma$ conversion is the Compton scattering of the laser light off the high energy electrons (laser target). Thus one can get the energy and luminosity in $\gamma\gamma$, γe collisions close to those in e+e- collisions: $E_\gamma \sim E_e$; $L_{\gamma\gamma} \sim L_{e\text{-}e\text{-}}$

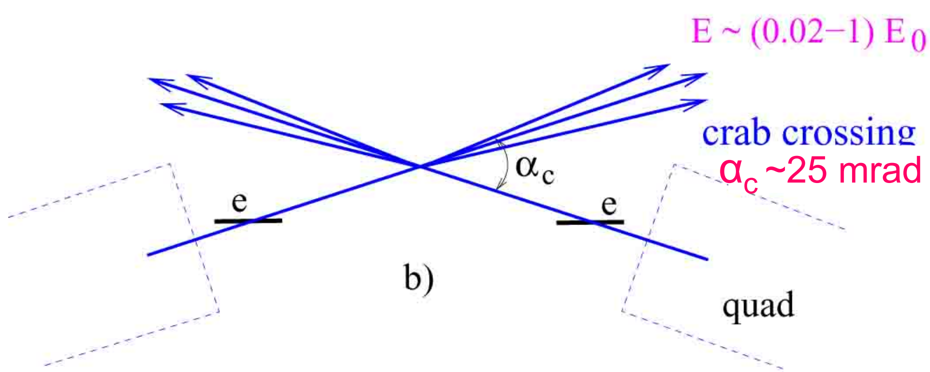
Linear colliders (projects)



Scheme of $\gamma\gamma$, γe collider



a)



b)

$$\omega_m = \frac{x}{x+1} E_0$$

$$x \approx \frac{4E_0\omega_0}{m^2c^4} \simeq 15.3 \left[\frac{E_0}{\mathrm{TeV}}\right]\left[\frac{\omega_0}{\mathrm{eV}}\right]$$

$E_0 = 250$ GeV, $\omega_0 = 1.17$ eV

(λ=1.06 μm) $\Rightarrow$ x=4.5

$\omega_m = 0.82 E_0 = 205$ GeV

$x = 4.8$ is the threshold for $\gamma\gamma_L \to e^+e^-$ at conv. reg.

ω_{max}~0.8 E_0

$W_{\gamma\gamma,\,max}$ ~ 0.8·2E_0

$W_{\gamma e,\,max}$ ~ 0.9·2E_0

Laser $e\to\gamma$ conversion

The method of the Compton scattering of laser light off high energy electrons was known since 1964 (Arutyunian, Tumanian, Milburn) and was used since 1966 at SLAC and other labs with $k=n_\gamma/n_e \sim 10^{-6}$.

For the photon collider one needs k~1 !

The required laser flash energy is about 1-10 J and ~1-3 ps durations and rep.rate similar to the linear collider (~10 kHz).

In 1981 we believed that it will be possible just extrapolating the progress in the laser technique (beside rep.rate was only 10-100 Hz).

In 1985 D.Strickland and G.Mourou invented the chirped pulse technique which made the photon collider realistic.

For the supercondicting ILC one can use the external optical cavity which considerably decreases the required laser power and together with other modern laser techniques (diode pumping, adaptive optics, multilayer mirrors) makes the photon collider really technically feasible.

First publications

1. I.Ginzburg, G.Kotkin, V.Serbo, V.Telnov, On posibility of obtaining gamma-gamma, gamma-electron beams with high energy and luminosity, Preprint INP 81-50, Feb.1981, Pizma ZhETF 34 (1981) 514; JETP Lett. 34 (1982) 91(265citations)
2. I.Ginzburg, G.Kotkin, V.Serbo, V.Telnov, Nucl.Insr.and Meth 205(1983) 47; (770c)
3. I.Ginzburg, G.Kotkin, S.Panfil, V.Serbo, V.Telnov, Nucl.Insr.&Meth A219 (1984) 5; (620c) (2 and 3 – detailed description of PLC principles: kinematics, polarization effects, luminosity spectra e.t.c.)

Very important

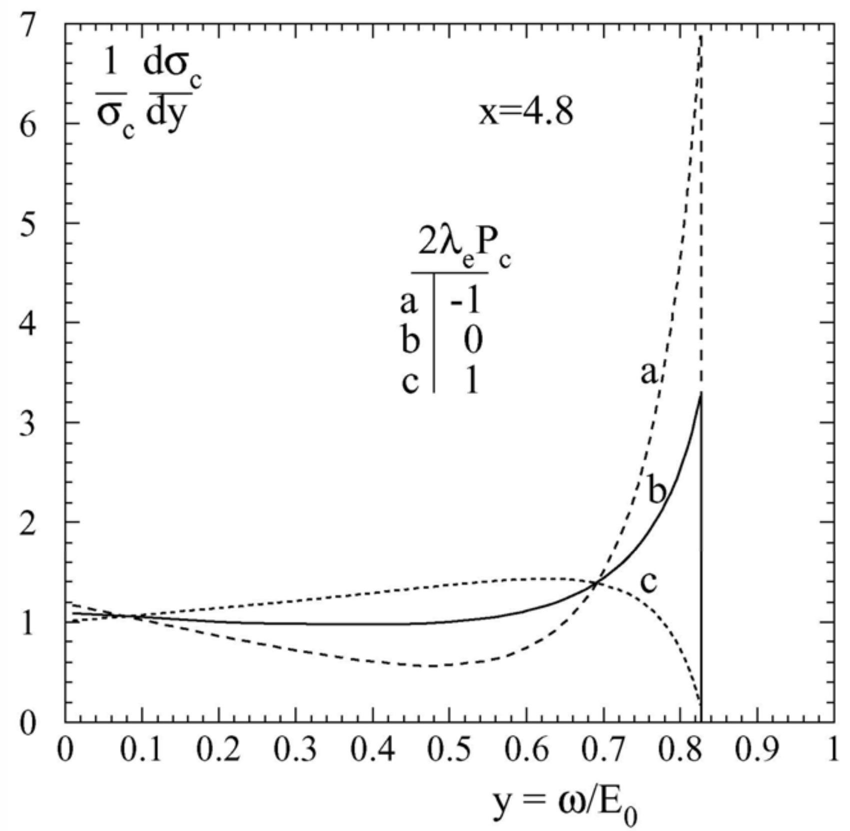
1. V.Telnov, Problems of obtaining $\gamma\gamma,\gamma e$ at lin.coll., Nucl.Insr.&Meth A294 (1990) 72; (390c) (Removal of beams (crab crossing), beam collision effects)
2. V.Telnov, Status of gamma gamma, gamma electron colliders (PHOTON99, May1999) Nucl.Phys.Proc.Suppl.82:359-366,2000. (“External” optical cavity for PLC at TESLA has been suggested)

Most full description of the PLC up to now

Badelek et al., Photon collider at TESLA (TESLA TDR), Int.J.Mod.Phys.A19: 5097-5186, 2004 (280c).

Electron to Photon Conversion

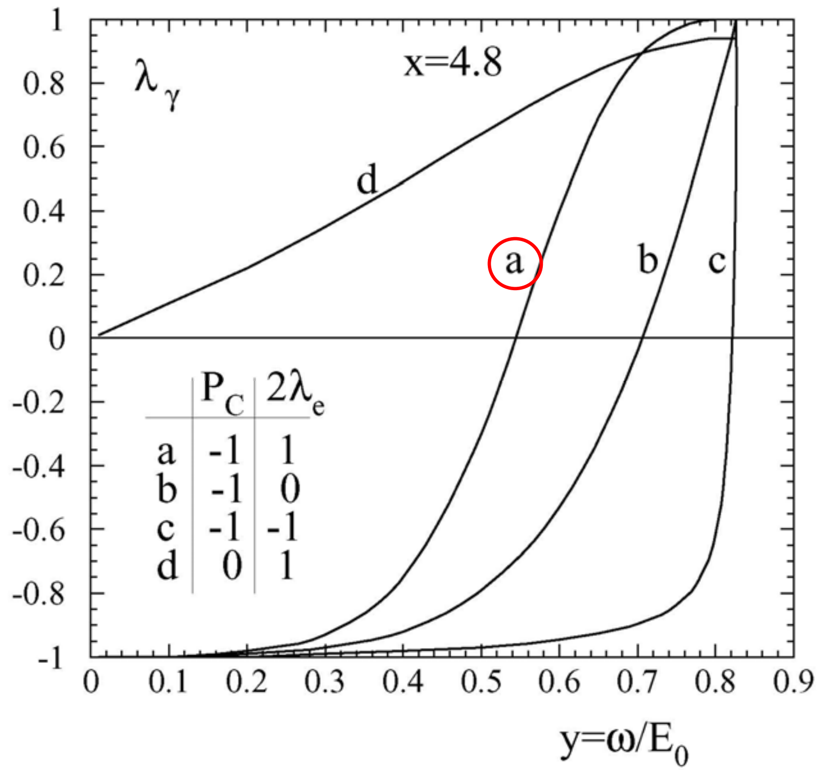
Spectrum of the Compton scattered photons



λ_e – electron longitudinal polarization

P_c – helicity of laser photons, $x \approx \frac{4E_0\omega_0}{m^2c^4}$

Mean helicity of the scattered photons ($x = 4.8$)



(in the case a) photons in the high energy peak have $\lambda_\gamma \approx 1$)

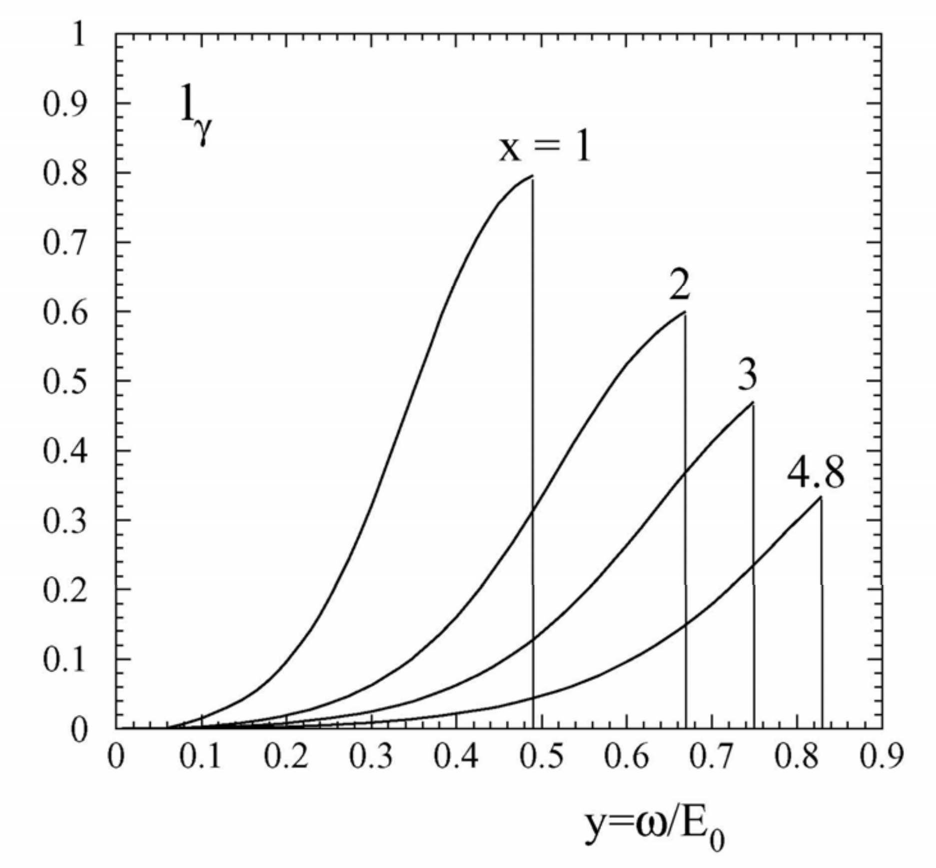
The cross section of the Higgs production

$$\sigma(\gamma\gamma \to h) \propto 1 + \lambda_1\lambda_2$$

The cross section for main backgound

$$\sigma(\gamma\gamma \to b\bar{b}) \propto 1 - \lambda_1\lambda_2$$

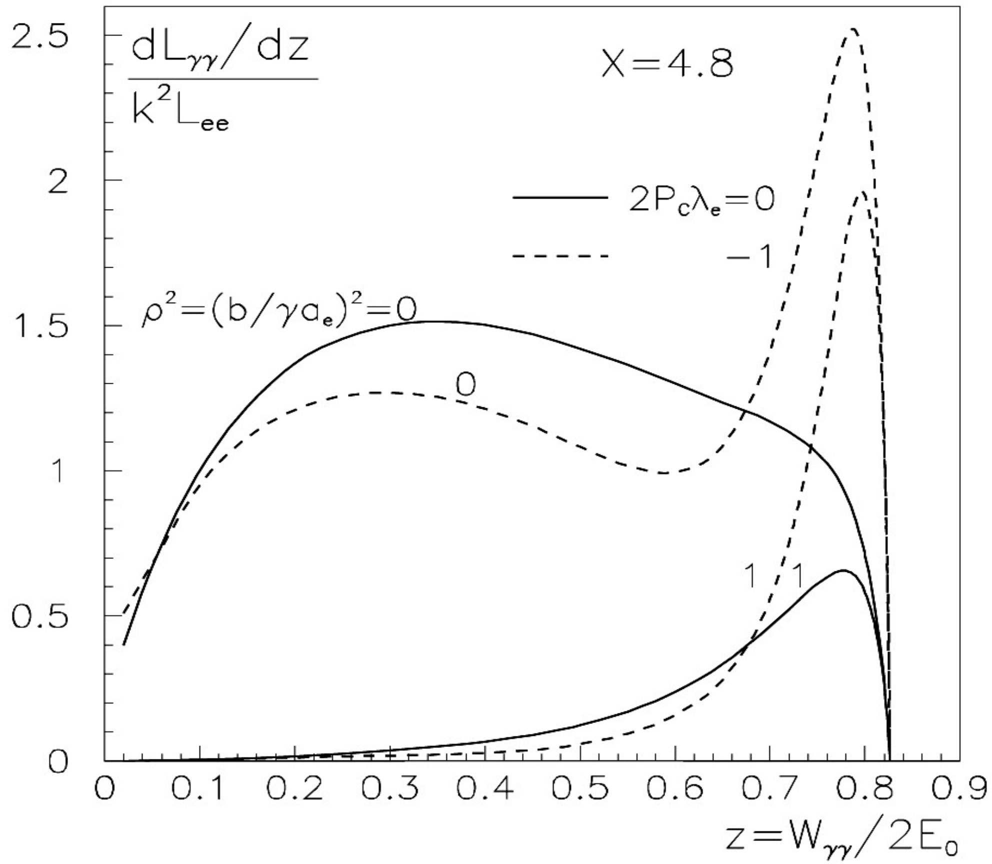
Linear polarization of photons



$\sigma \propto 1 \pm l_{\gamma 1} l_{\gamma 2} \cos 2\varphi$ ± for CP=±1

Linear polarization helps to separate H and A Higgs bosons

Ideal luminosity distributions, monohromatization



Due to angle-energy correlation high energy photons collide at smaller spot size, providing some monochromatization of $\gamma\gamma$ collisions.
This needs $b/\gamma > a_e$.

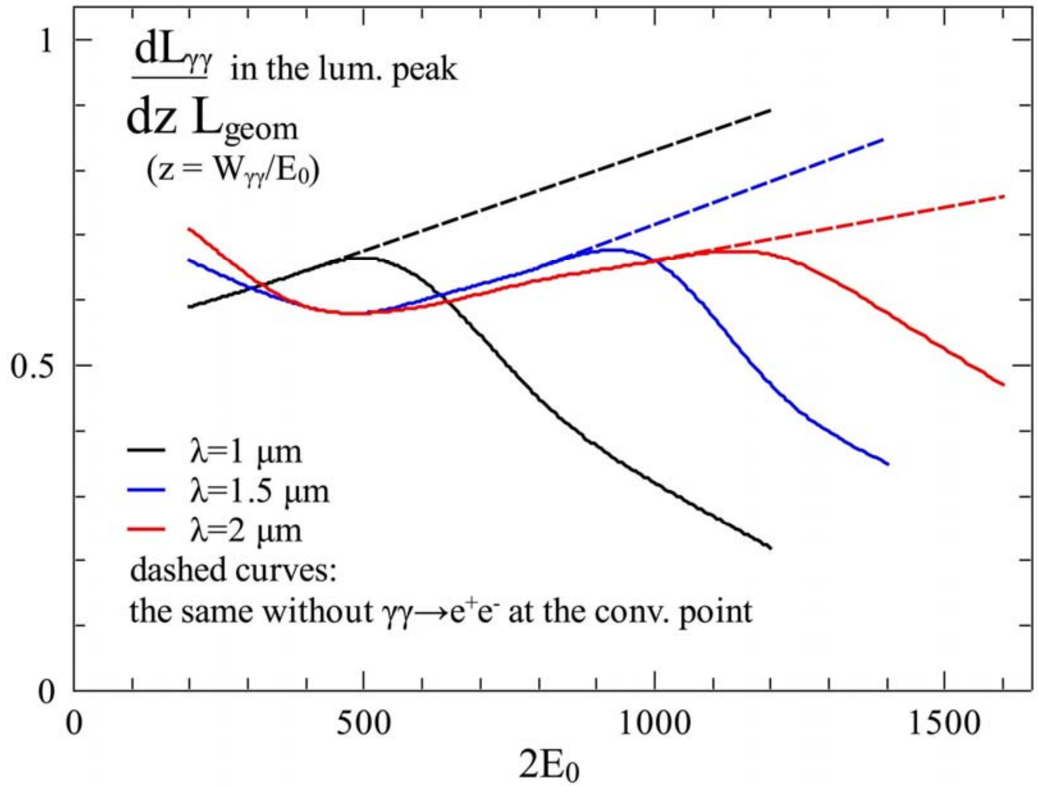
The optimum laser wavelength

The maximum energy of photons after the Compton scattering

$$\omega_{\max} \approx \frac{x}{x+1} E_0, \qquad x = \frac{4E_0\omega_0}{m^2c^4}$$

For x>4.8 the luminosity in the high energy lum. peak decreases due to e+e- pair creation in collision of laser and high energy photons at the conversion point.
For the maximum collider energy E_0 the optimum laser wave length (x=4.8) is

$$\lambda\,[\mu\mathrm{m}] \approx 4E_0[\mathrm{TeV}]$$



λ=1 μm for $2E_0$<500-600 GeV,
λ=2 μm for $2E_0$<1.2 TeV

Laser flash energy

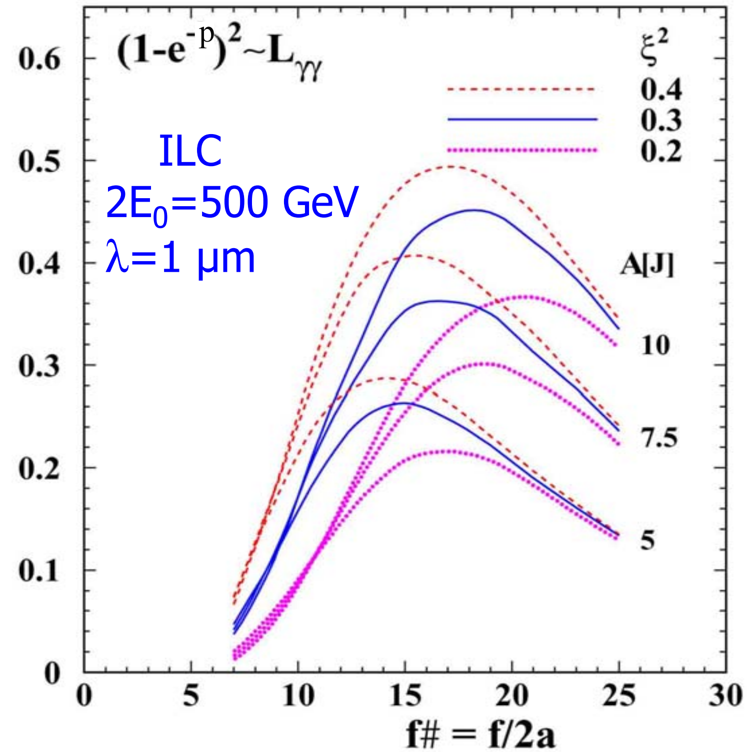
For $e \to \gamma$ conversion one needs thickness (t) of laser target equal about one Compton collision length ($p = t/\lambda_C \sim 1$). The required flash energy is determined by σ_c , geometric properties of laser and electron beams and by nonlinear effects in Compton scattering described by parameter $\xi^2 = \dfrac{e^2 \overline{F}^2 \hbar^2}{m^2 c^2 \omega_0^2} = \dfrac{2 n_\gamma r_e^2 \lambda}{\alpha}$ which should be kept small (0.15-0.3),

because $\omega_m = \dfrac{x}{x+1+\xi^2} E_0$.

It is reasonable to keep

$$\Delta\omega_m / \omega_m \approx \xi^2 / (x+1) < 0.05$$

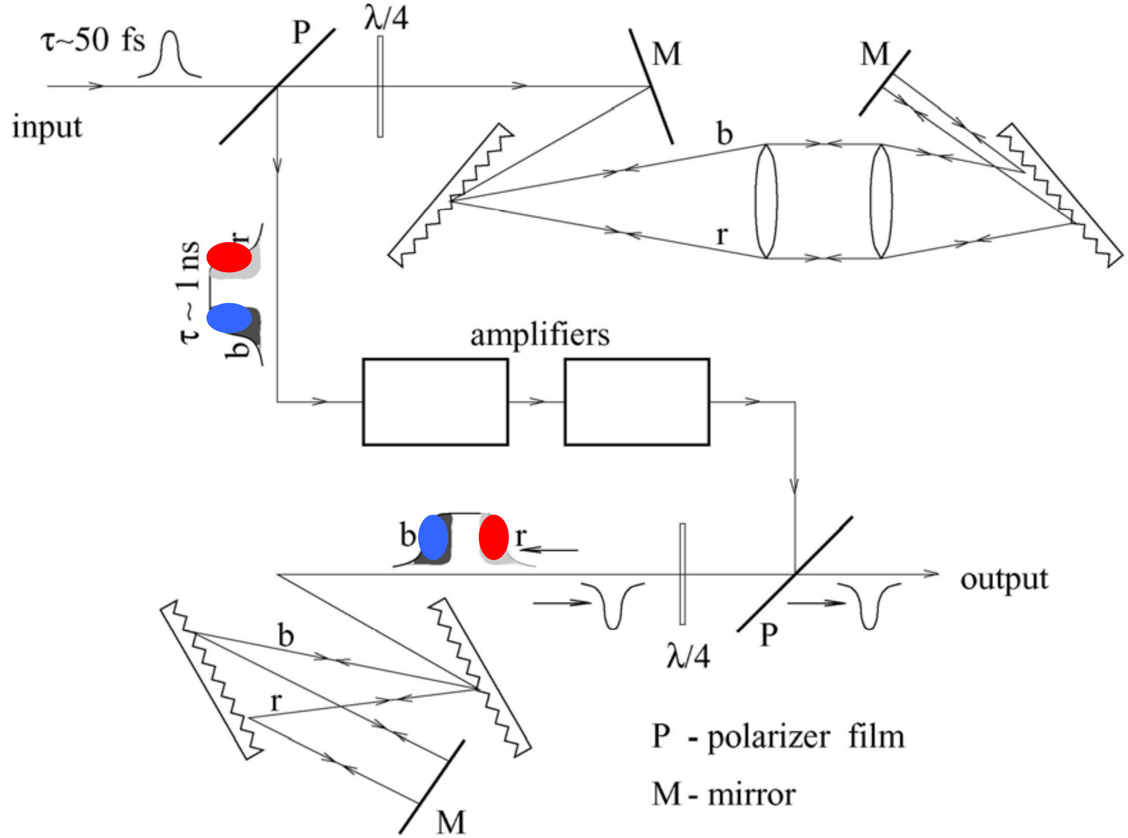
then for $x = 4.8$ $\xi^2 < 0.3$



For $\lambda = 1$ μm ($2E_0$=500 GeV) the required flash energy is about A~10 J and it increases for larger λ (or E_0) due to the nonlinear effect. It is determined by laser diffraction and geometric beam parameters at short λ and by nonlinear effects at large λ (multiTeV collider).

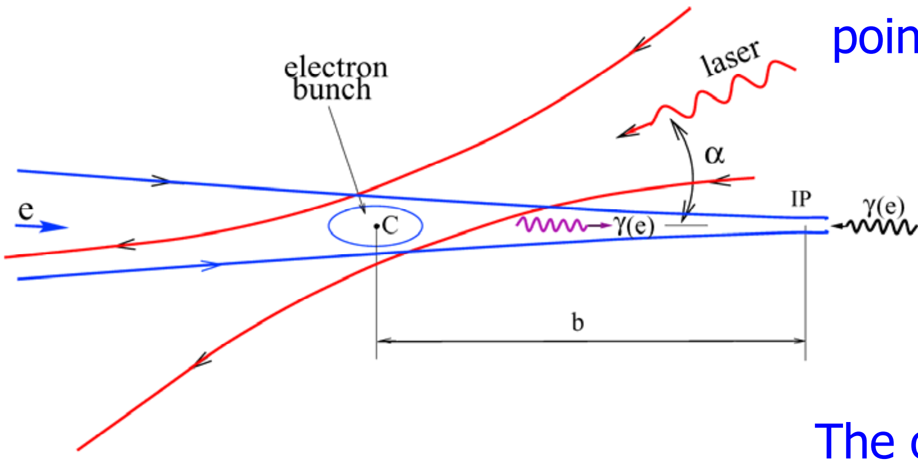
Chirped pulse laser technique (D.Strickland, G.Mourou, 1985) made photon colliders idea really feasible

Stretching-amplification-compression allows to avoid nonlinear effects (self-focusing) during amplification and thus to increase laser a power by a factor of 1000! Tens Joule pulses of ps duration became a reality.

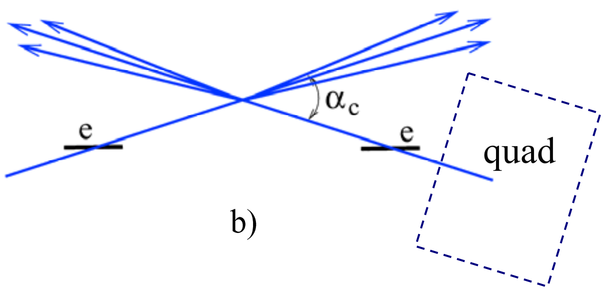


Other technologies important for the photon collider: diode pumping, adaptive optics, high reflective multilayer mirrors for high powers – all is available now.

Collision scheme



a)



b)

Minimum distance (b) between the interaction point (IP) and conversion point (CP)

$$b \approx 3\sigma_z + 0.1E[\mathrm{TeV}],\ \ \mathrm{cm}$$

2-nd term is the distance equal to one Compton collision length at x=4.8 and ξ^2=0.3.

The optimum CP-IP distance corresponds to the case when an additional transverse size due to photon divergence in Compton scattering is equal to electron beam size

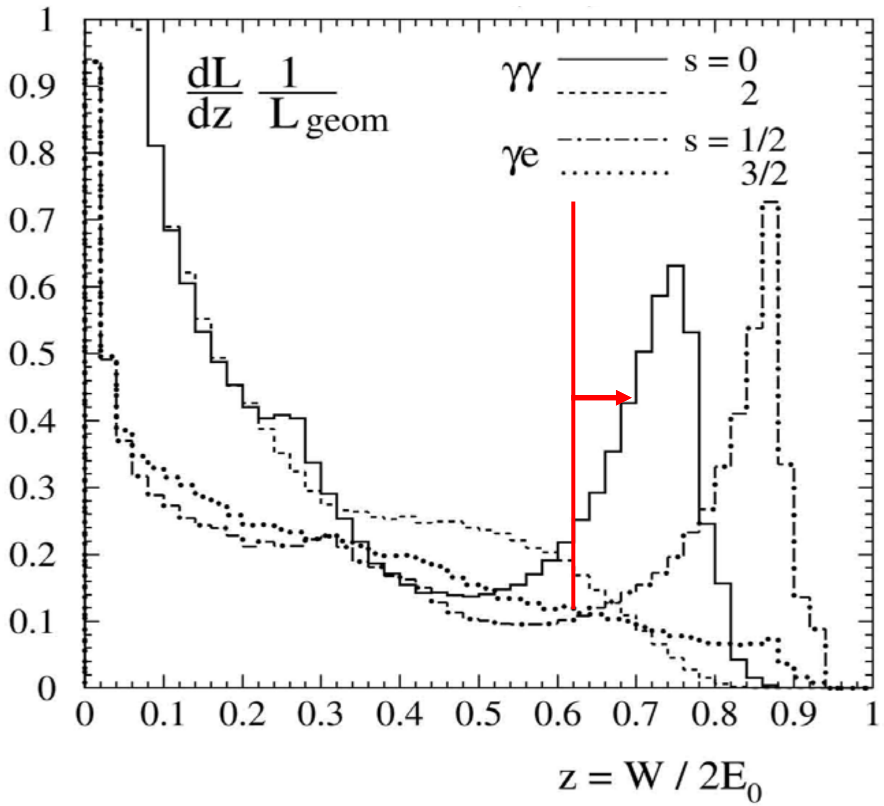
$$\sigma_y \sim b/\gamma$$

For ILC(500) σ_y ~5 nm → b ~ 2.5 mm

Typical $\gamma\gamma$, γe luminosity spectra

simulation with account all important effect at CP and IP regions:
multiple Compton scattering in CP, beamstrahlung, coherent pair creation, beam repulsion e.t.c.

ILC(500)

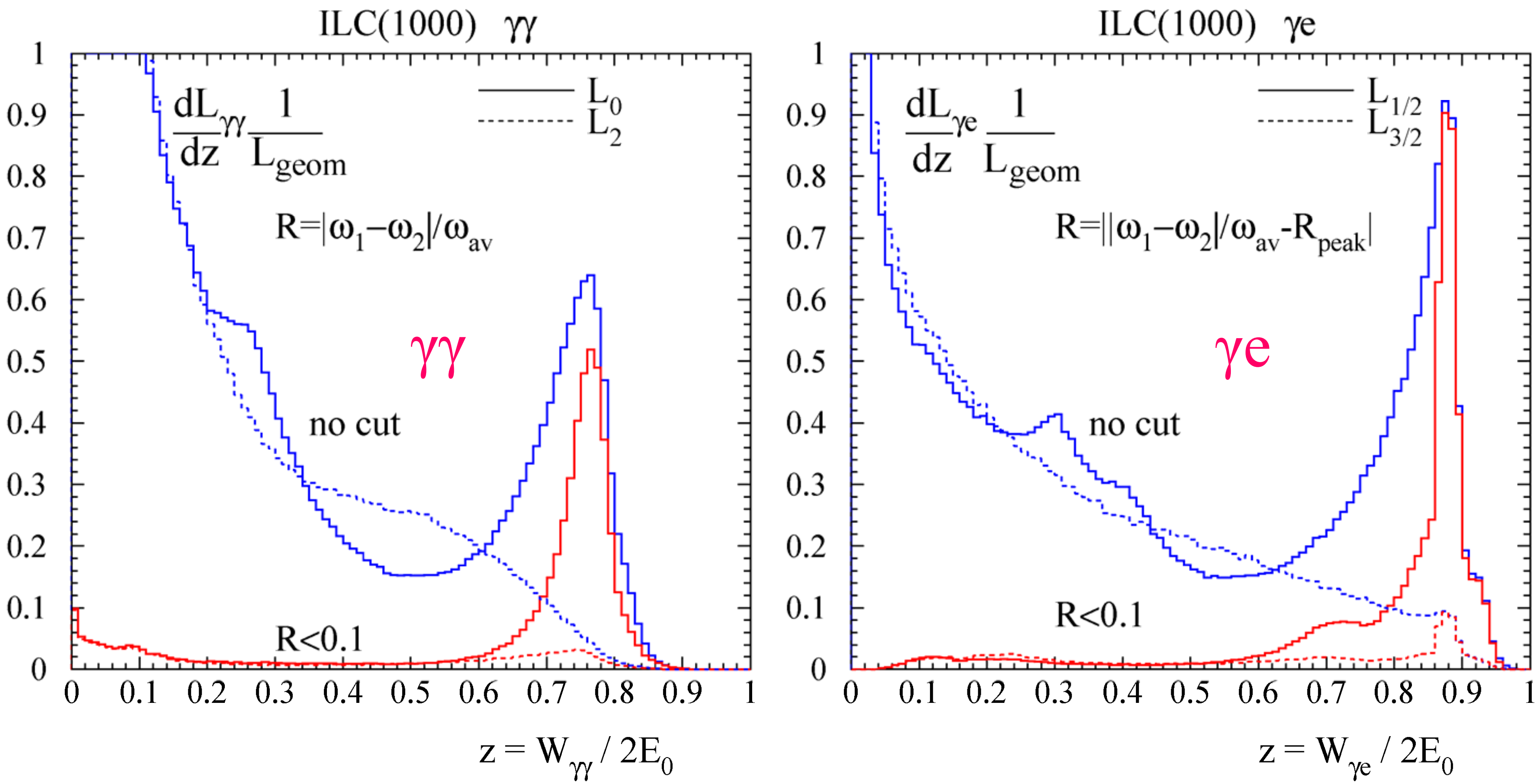


Luminosity spectra and their polarization properties can be measured using QED processes

$L_{\gamma\gamma}(z>0.8z_m) \sim 0.1\ L_{e\text{-}e\text{-}}(geom)$

Luminosity spectra at ILC(1000) with λ=2 μm

(red curves with restriction on longitudinal momentum of produced system)



Such γγ collider would be the best option for study of X(750)

(fake γγ peak observed at LHC in 2015-2016)

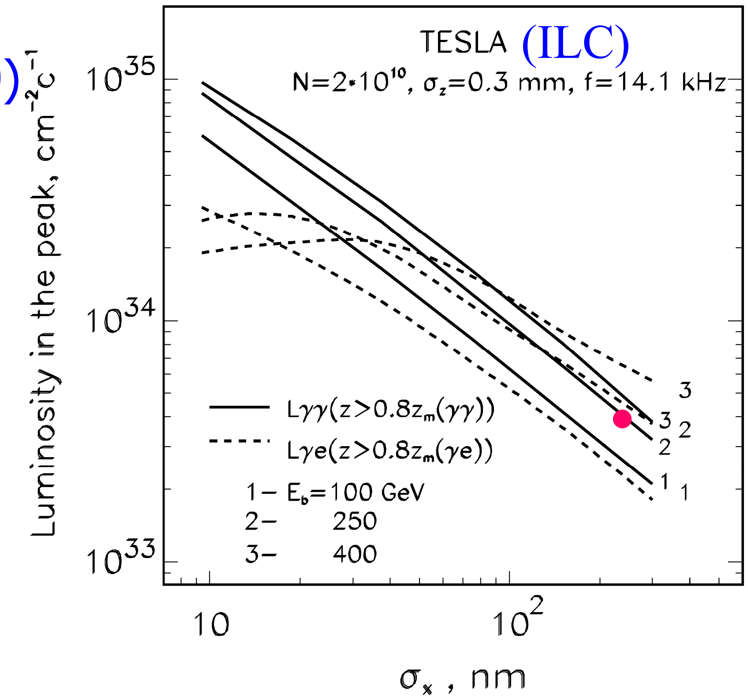
Factors limiting $\gamma\gamma,\gamma e$ luminosities

Main collision effects at the IP:

- $\gamma\gamma$ •coherent pair creation($\chi\approx$0.1-10)
- $\gamma\gamma$, γe •beamstrahlung ($\Upsilon\approx$0.1-10)
- γe,ee •beam-beam repulsion

Coherent pair creation:

high energy photons convert to e+e- pair on the field of the opposing electron beam, it is the only collision effect limiting γγ-luminosity, important for multi-TeV colliders and short beams.



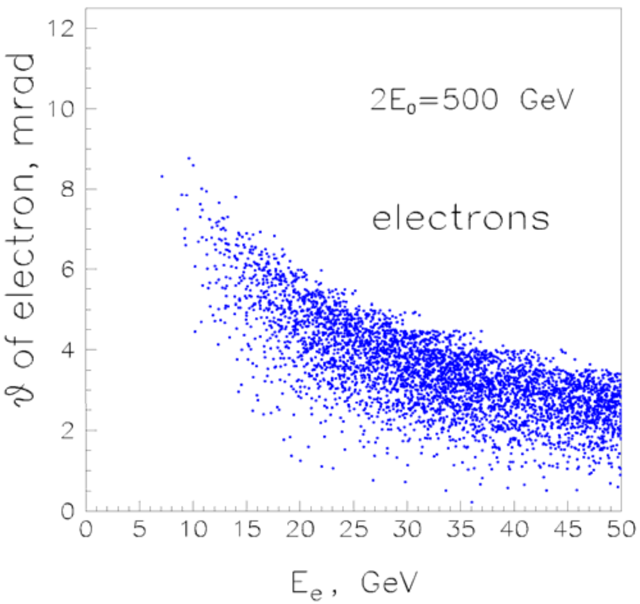
•with damping rings

At ILC σ_x~200-300 μm (limited by emittances). This figure shows that one order higher luminosity is possible with smaller beam sizes.

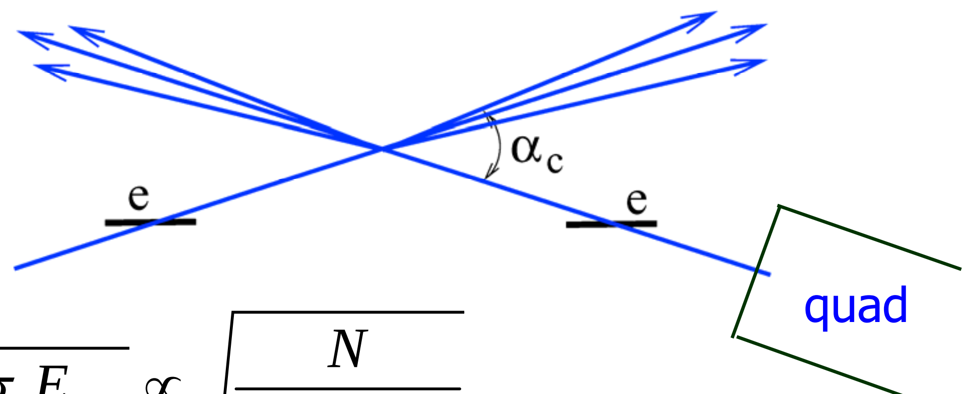
For 2E<1 TeV the γγ-luminosity is determined only by geometric e-e- luminosity, which depends on beam emittances: $L \propto 1/\sqrt{\varepsilon_{nx}\varepsilon_{nx}}$.

At present electron guns give the product of emittances several times larger than with damping rings, further improvements of electron sources (polarization is very desirable) are needed for photon colliders without damping rings.

Removal of disrupted beams, crossing angle, beamdump



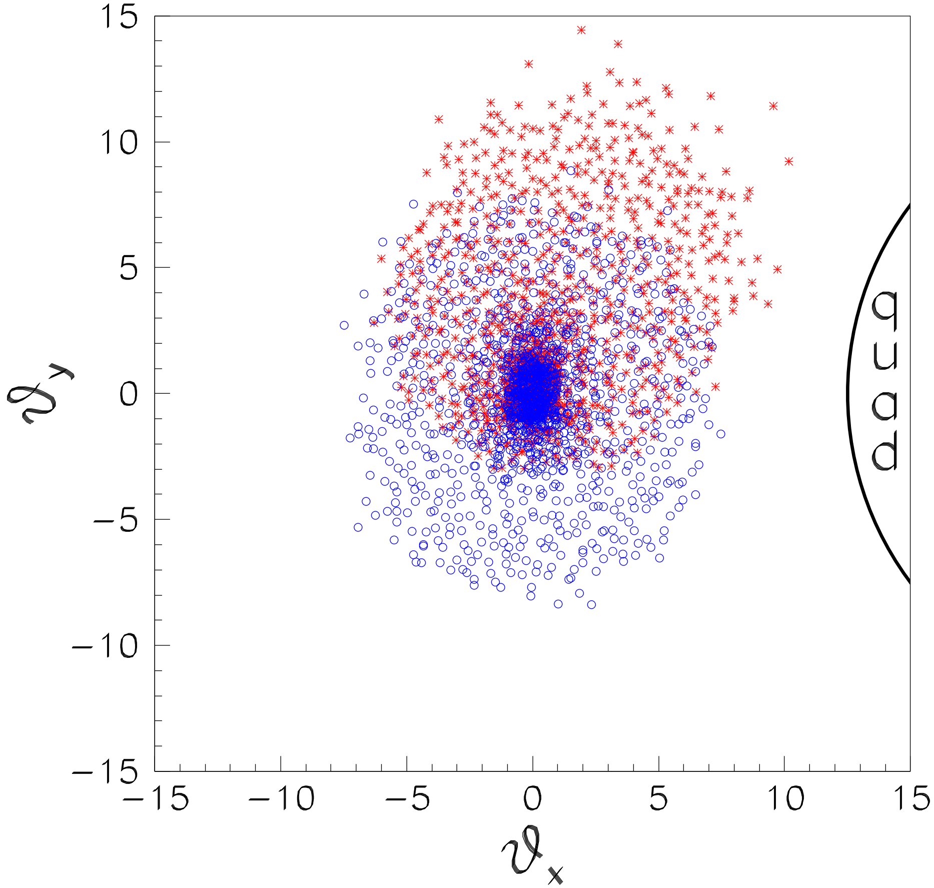
Removal of disrupted beams from the detector is one of most serious problem for the photon collider. After the interactions beams have very wide energy spread: $E \approx (0.02\text{-}1)E_0$ and large disruption angle (about 10 mrad at ILC). The problem is solved by using crab-crossing scheme where beams travels outside final quads.

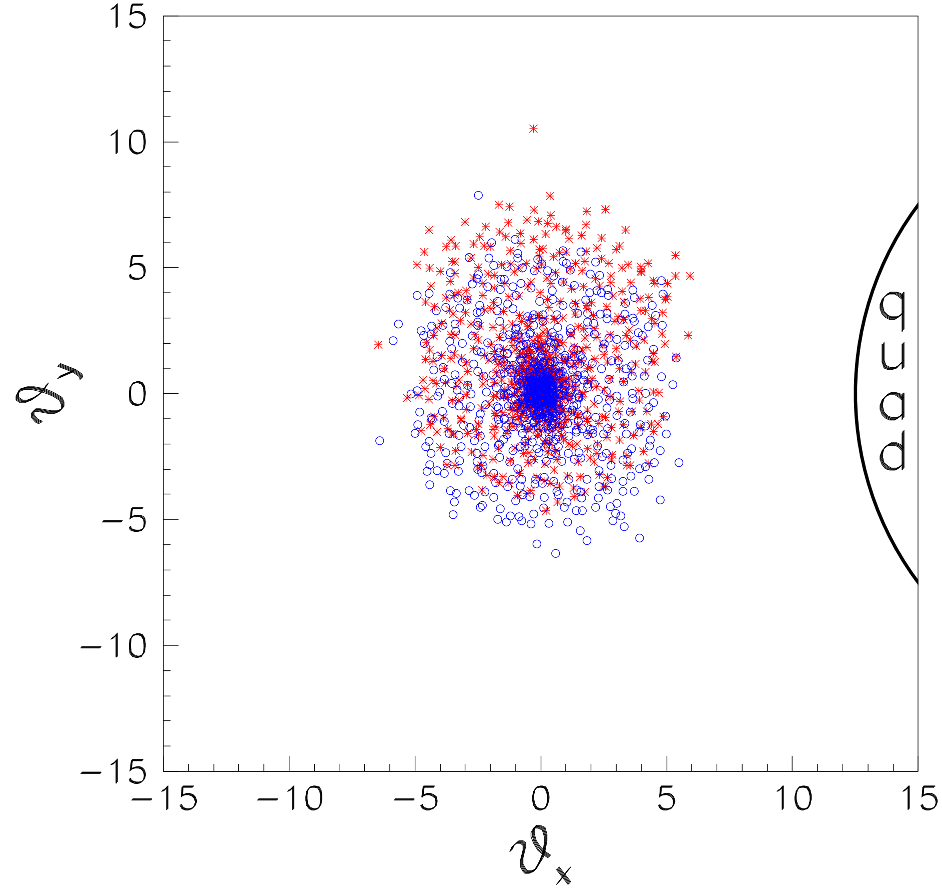


$$\theta_d \propto \sqrt{N/\sigma_z E_{\min}} \propto \sqrt{\frac{N}{\sigma_z \sigma_c(x)\lambda}}$$

Angular size of quads 5/400~12 mrad, so for PLC at ILC crossing angle about 25 mrad is needed (14 mrad is now for e+e-). Using λ =2 μm (instead of 1 μm) allows to decrease α_c from 25 to 20 mrad, this solution completely compatible with e+e-.

Disrupted beam with account of the detector field (at the front of the first quad at L=4 m)





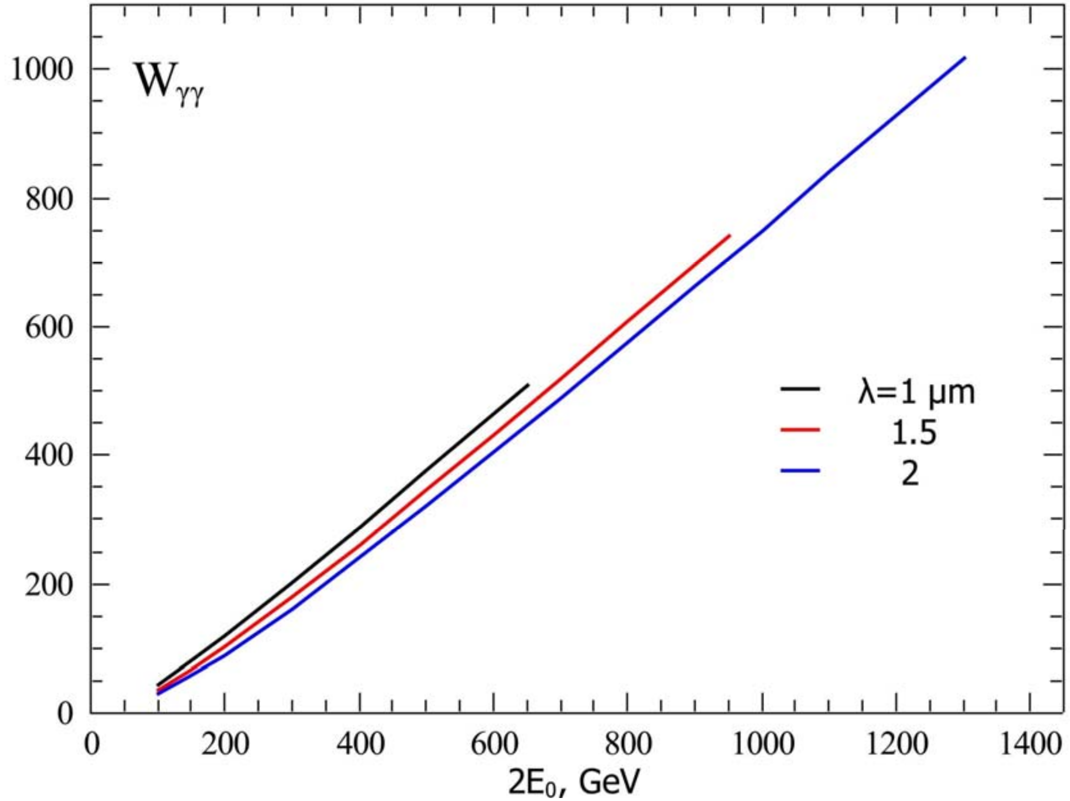
$2E_0$=500 GeV, λ=1 μm

E_{min}≈5 GeV

α_c=25 mrad → α_c=20 mrad

$2E_0$=1000 GeV, λ=2 μm

The dependence of $W_{\gamma\gamma}$ on the laser wavelengh



Here $W_{\gamma\gamma}$ corresponds to the peak of lum. spectra

The energy $2E_0$ required for the study of the H(125) and top threshold

λ, μm	1	1.5	2	
H (125)	210	235	255	21%
top(360)	485	520	550	13.4%

In order to have at the PLC with λ=2 μm the same energy reach as with λ=1 μm with $2E_0$=500 GeV one need $2E_0$=565 GeV (or 13% higher only).

Crossing angle

It is important to make the ILC design compatible with the photon collider.

Now for e+e- the crossing angle α_c=14 mrad

For photon collider one needs α_c~25 mrad (because larger disruption angles)

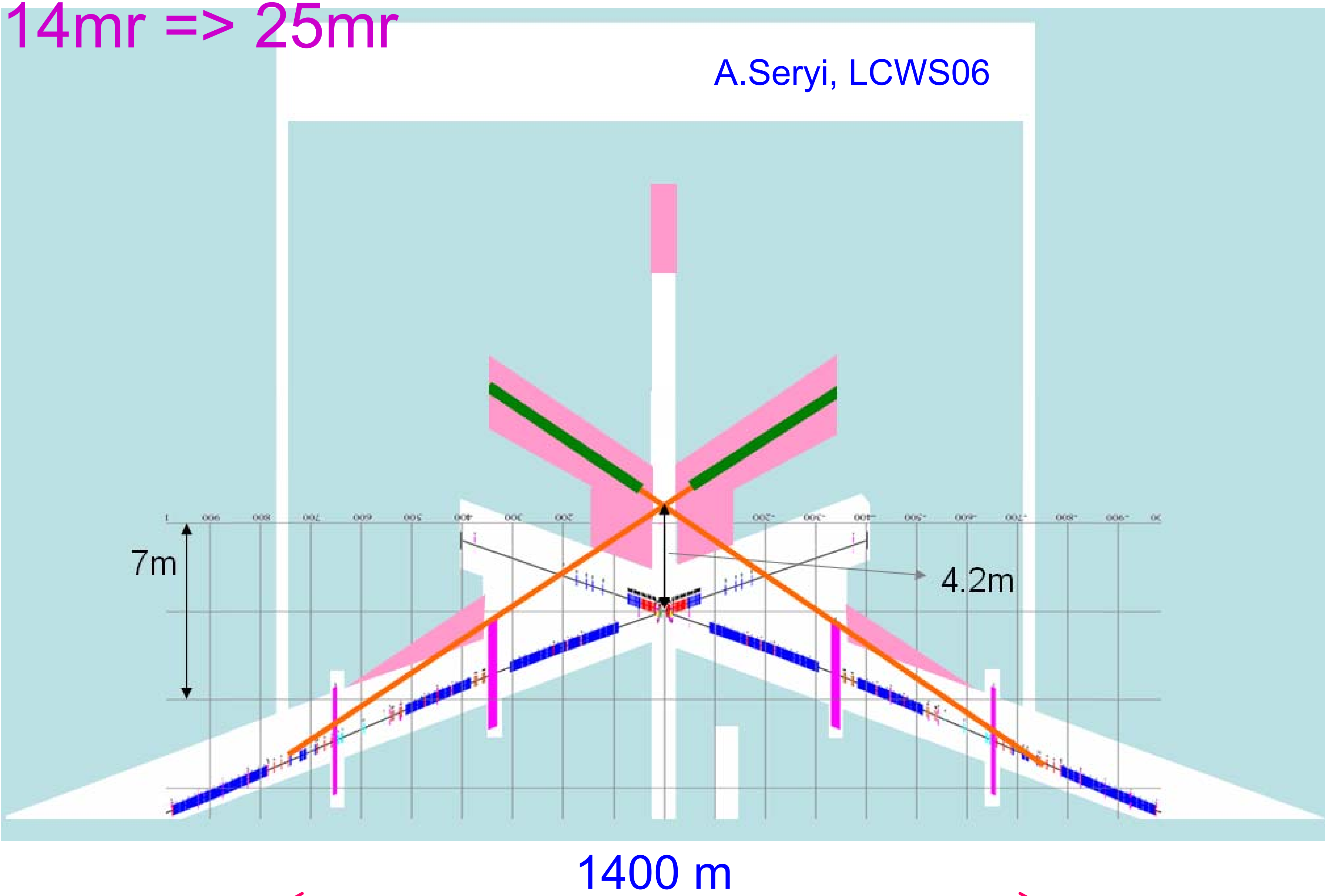
Dependence of $L_{\gamma\gamma}$ on α_c:

25 mrad	1
23 mrad	~0.76
20 mrad	~0.43
14 mrad	~0

CLIC needs 20 mrad.

So, the ILC team should change α_c=14 to 25 mrad in order to have in future the possibility of CLIC and PLC in the same tunnel !

14mr => 25mr



- additional angle is 5.5mrad and detector need to move by about 3-4m

CLIC
2 IP, with 20 and 25.5 mrad

12th Int. Particle Acc. Conf. IPAC2021, Campinas, SP, Brazil JACoW Publishing
ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB013

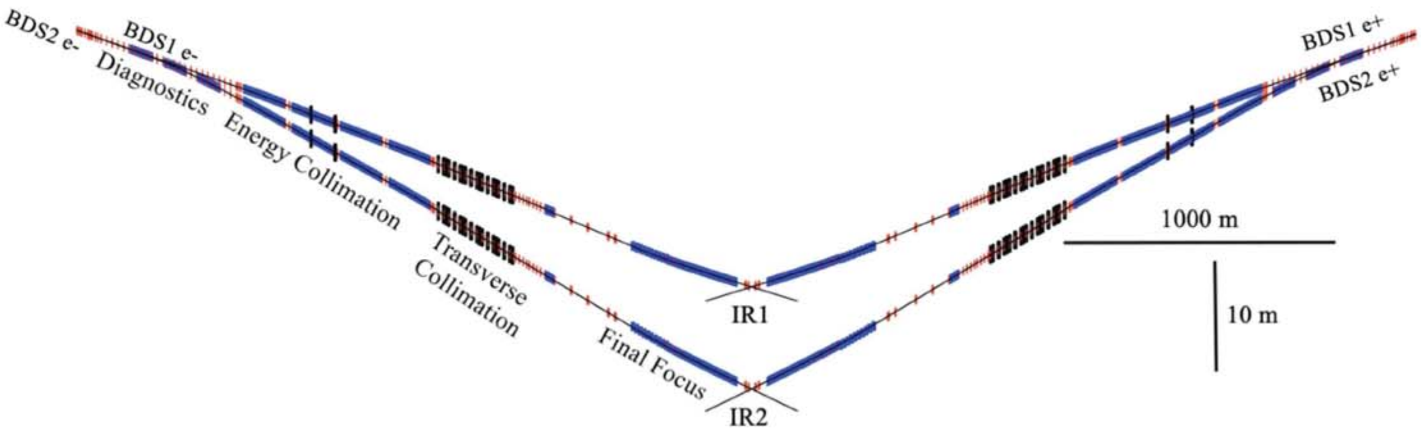
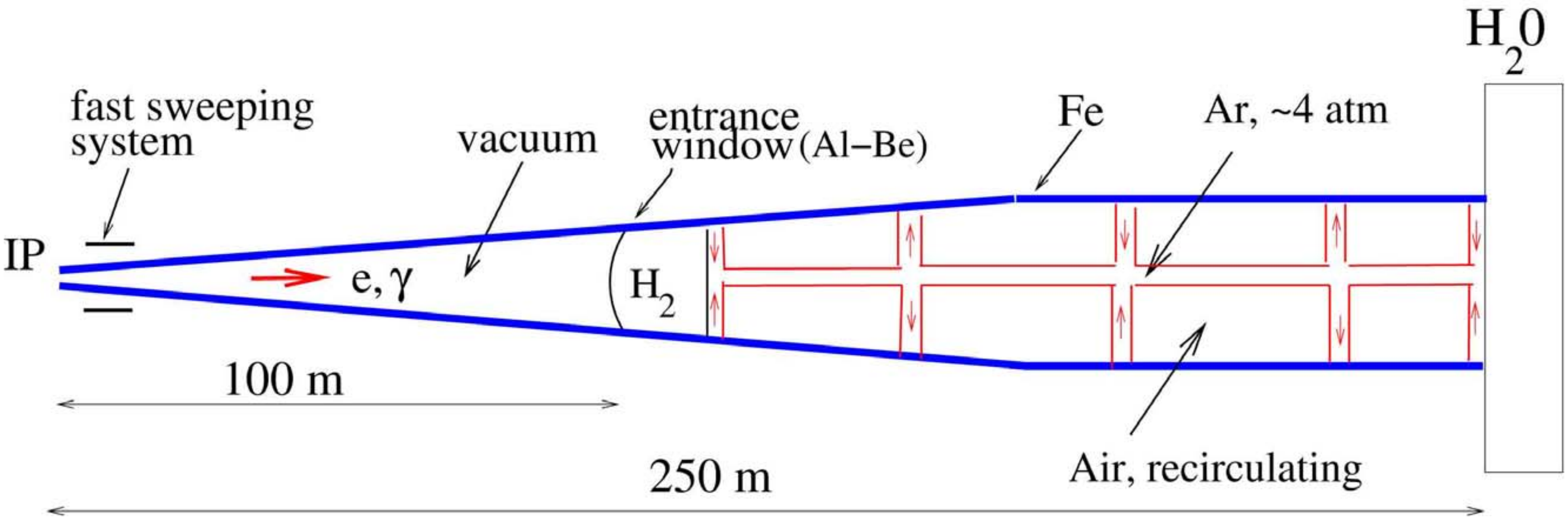


Figure 3: Layout of the new dual CLIC 3 TeV BDS System for two IRs.

May be ILC needs similar design (instead of pull-push)

Photon collider produces a very narrow powerful gamma beam (and a wide electron beam) therefore a special beam dump is needed

Possible solution



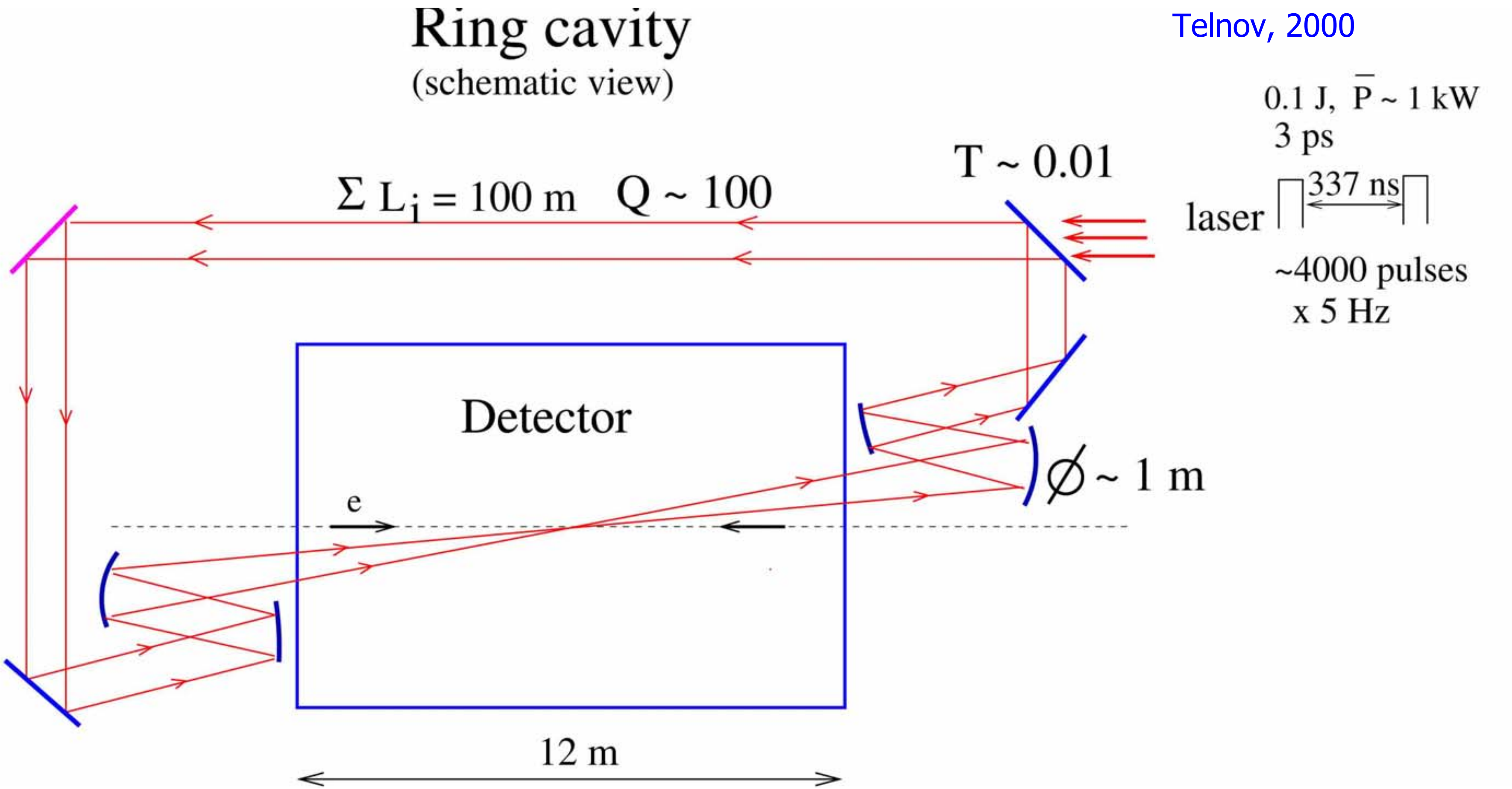
Requirements for the ILC laser system

- Wavelength ~1 μm (good for 2E<0.8 TeV)
- Time structure Δct~100 m, 3000 bunch/train, 5 Hz
- Flash energy ~5-10 J
- Pulse dutation ~1-2 ps

If a laser pulse is used only once, the average required power is P~150 kW and the power inside one train is 30 MW! Fortunately, only 10^{-9} part of the laser photons is knocked out in one collision with the electron beam, therefore the laser bunch can be used many times.

The best is the scheme with accumulation of very powerful laser bunch is an external optical cavity. The pulse structure at ILC (3000 bunches in the train with inter-pulse distance ~100 m) is very good for such cavity. It allows to decrease the laser power by a factor of 100-300.

Laser system

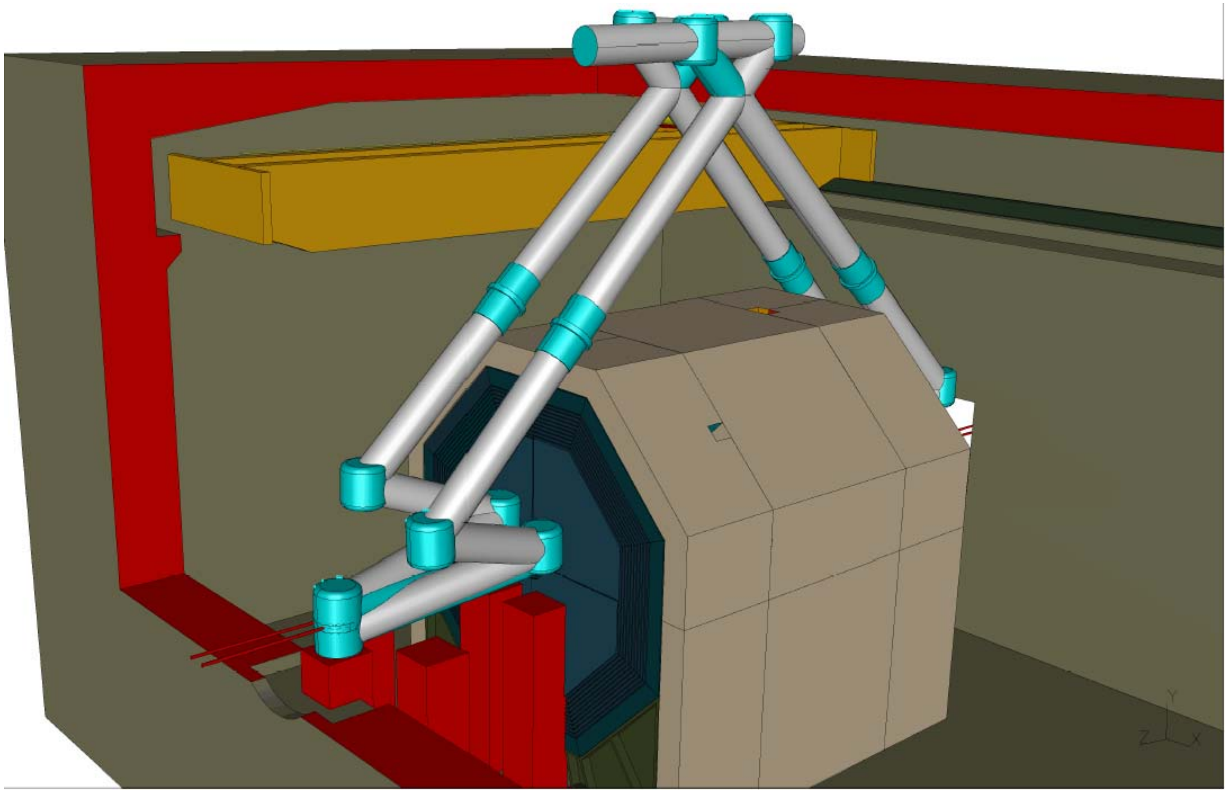


The cavity includes adaptive mirrors and diagnostics. Optimum angular divergence of the laser beam is ±30 mrad, A≈9 J (k=1), $\sigma_t \approx$ 1.3 ps, $\sigma_{x,L}$~7 μm

View of the detector with the laser system

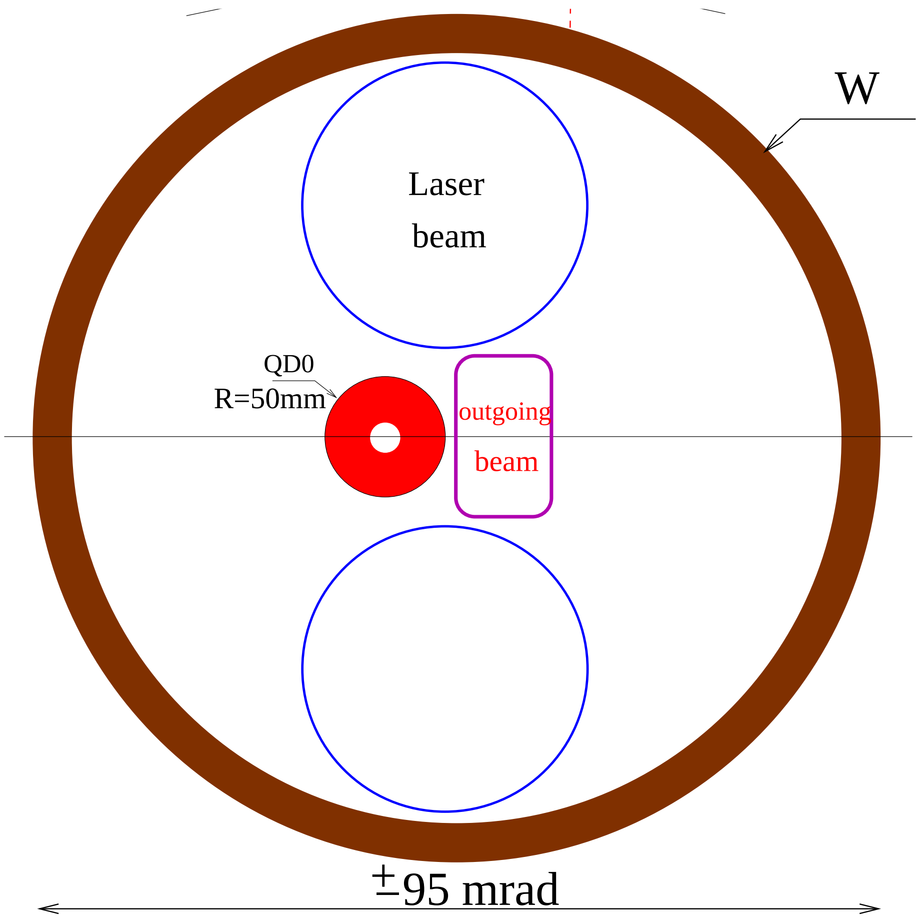
(the pumping laser is in the building at the surface)

DESY-Zeuten design (2005)



Here all mirrors are outside the detector which make life easier.
Disadvantage – too big first mirrors (d>1m).

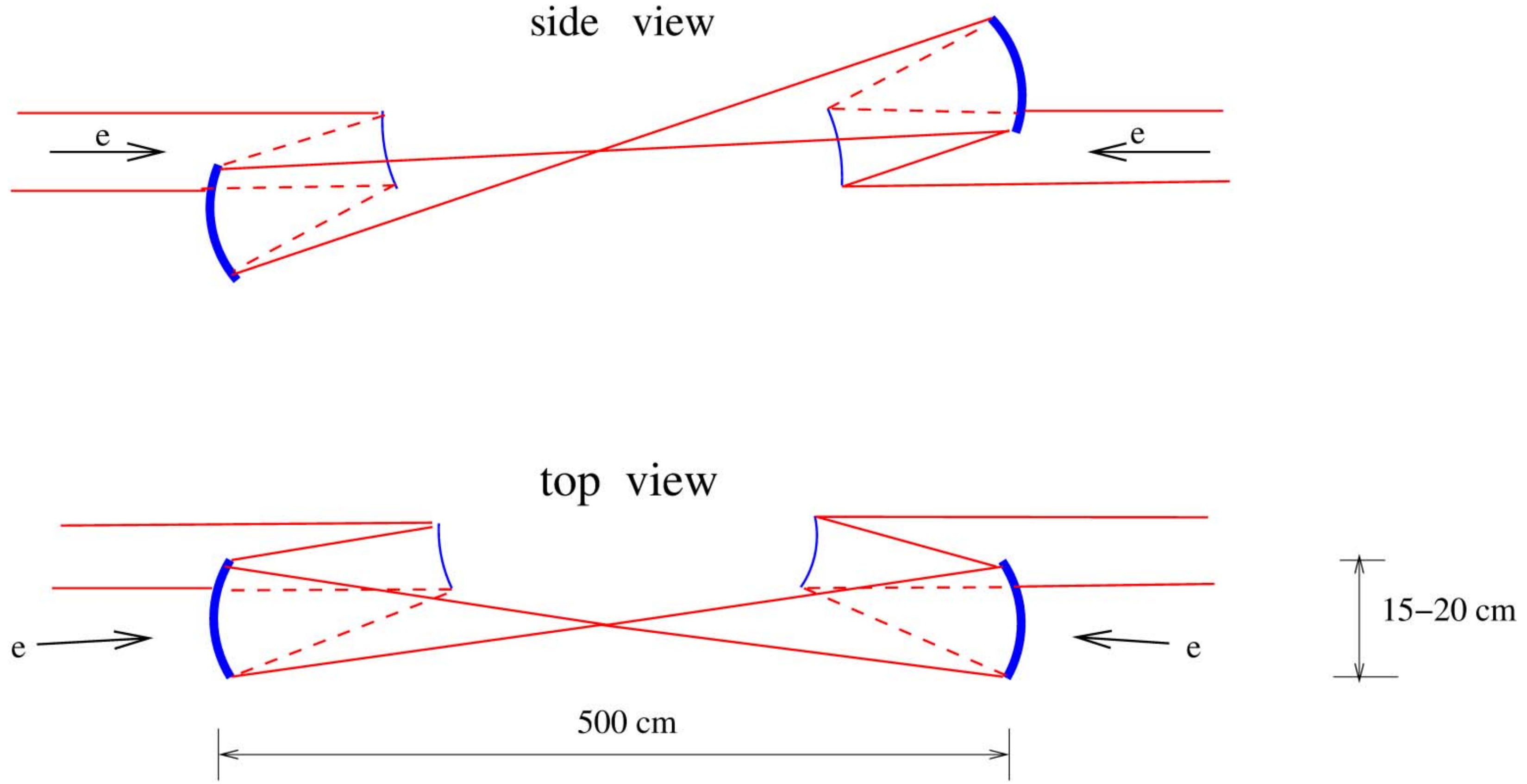
Layout of the quad, electron and laser beams at the distance 4 m from the interaction point (IP)



Another approach of laser optics inside the detector:

First mirrors with diameters 15 cm are placed at a distance 2-3 m from IP. In this scheme at least 4 mirrors for each of 2 lasers should be placed inside the detector in order to enter and output laser beams from the detector

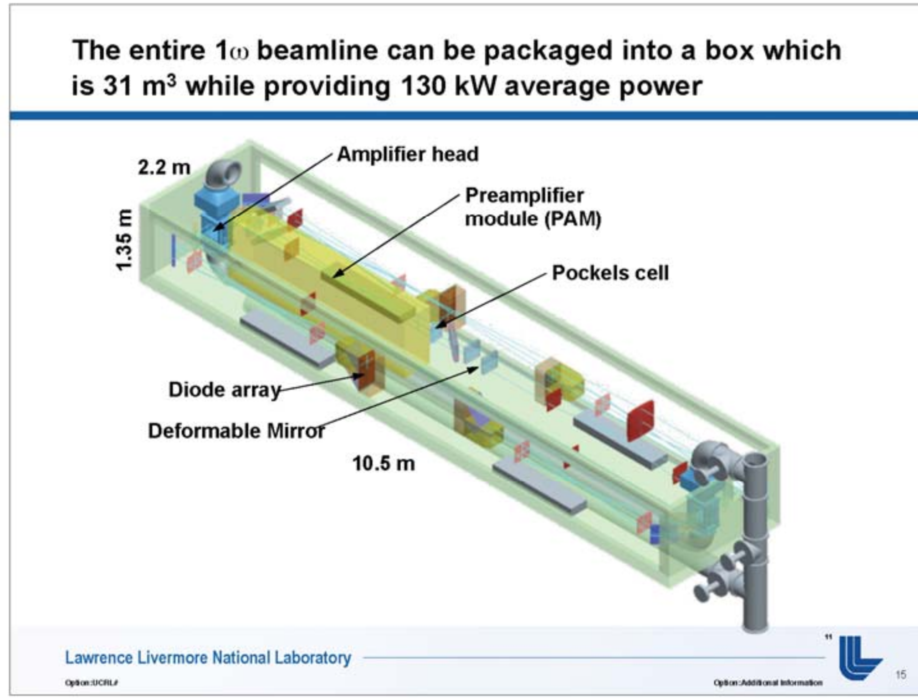
below only one of two laser beams is shown



Recently new option has appeared, one pass laser system, based on new laser ignition thermonuclear facility

Project LIFE, LLNL 16 Hz, 8.125 kJ/pulse, 130 kW aver. power

(the pulse can be split into the ILC train)



Laser diodes cost go down at mass production, that makes one pass laser system for PLC at ILC and CLIC realistic!

(The project LIFE was closed in 2014, because it was decided to get ignition with existing NIF)

Laser system for CLIC

Requirements to a laser system for PLC at CLIC (500)

Laser wavelength	~ 1 μm (5 for 2E=3000 GeV)
Flash energy	A~5 J, τ~1 ps
Number of bunches in one train	354
Length of the train	177 ns=53 m
Distance between bunches	0.5 ns
Repetition rate	50 Hz

The train is too short for the optical cavity, so one pass laser should be used.

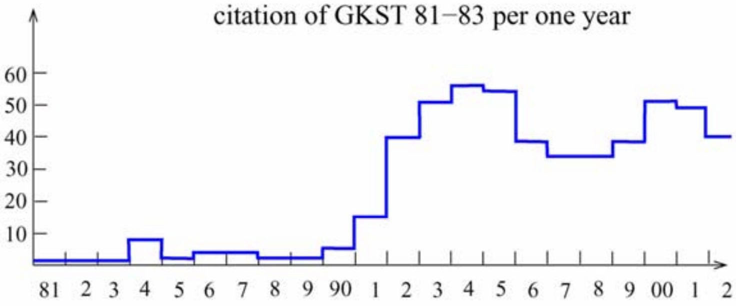
The average power of one laser is 90 kW (two lasers 180 kW).

One pass laser system, developed for LIFE (LLNL) is well suited for CLIC photon collider at 2E=500 GeV.

MultiTeV CLIC needs lasers with longer wavelength: $\lambda \approx 4E_0$[TeV], μm

Activity on photon colliders

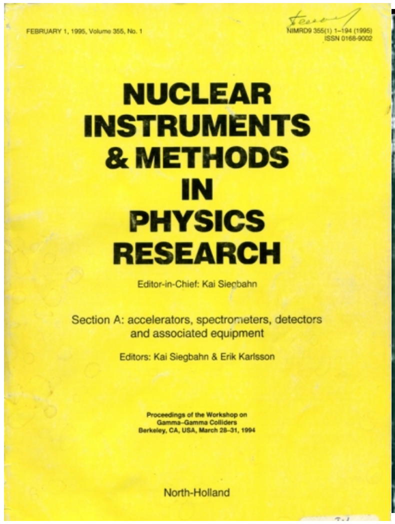
citation of GKST 81–83 per one year



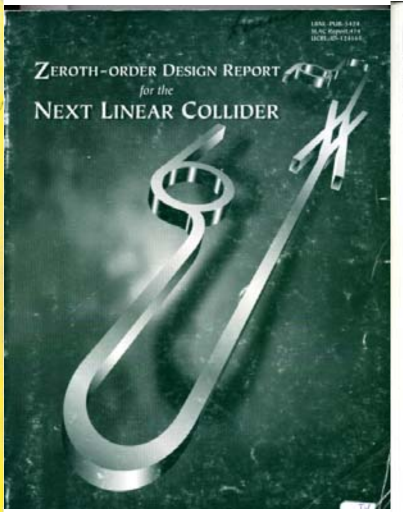
(total number of publications is larger by a factor of 2)

→ about 2 papers/week

γγ workshop LBL, 1994

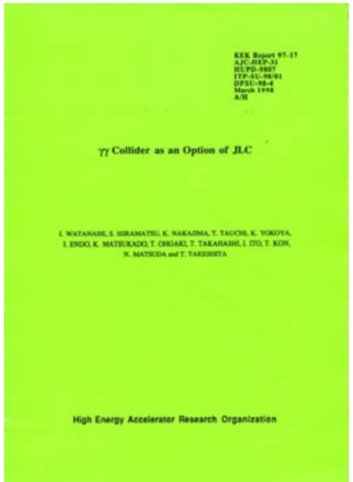


NLC-1996

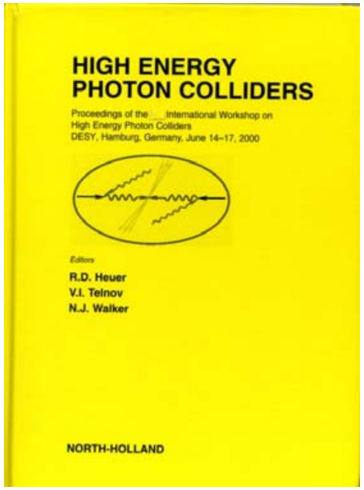


TESLA CDR-1997

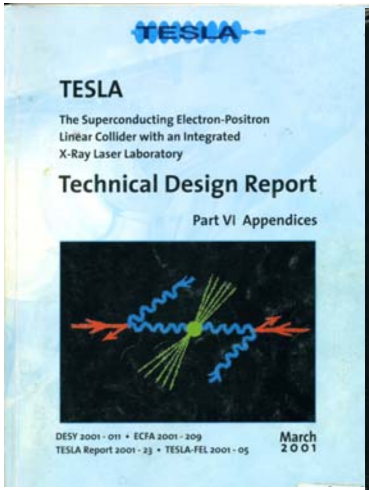
γγ at JLC



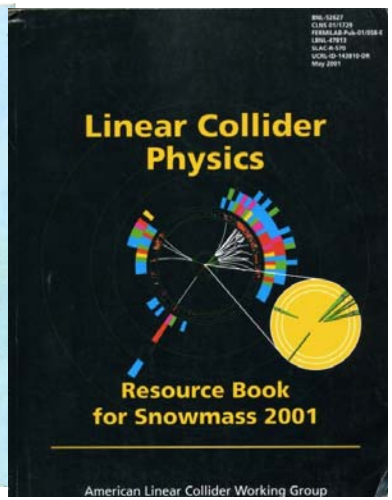
γγ workshop at DESY



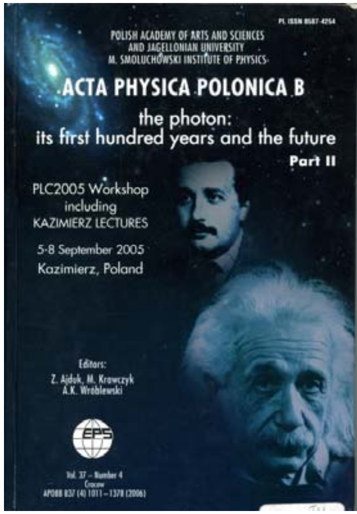
TESLA TDR



γγ NLC



PLC 2005



Photon colliders were suggested in 1981 and since ~1990 are considered as a natural part of all linear collider projects.

After the discovery of the Higgs boson many $\gamma\gamma$ Higgs factories projects appeared in 2012-2013 years

CERN

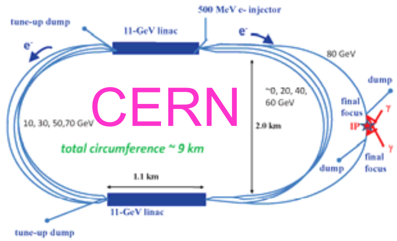
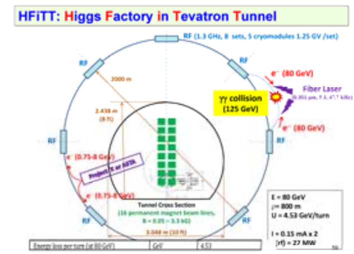


Figure 3: Sketch of a layout for a $\gamma\gamma$ collider based on recirculating superconducting linacs – the SAPPHiRE concept.

SLAC

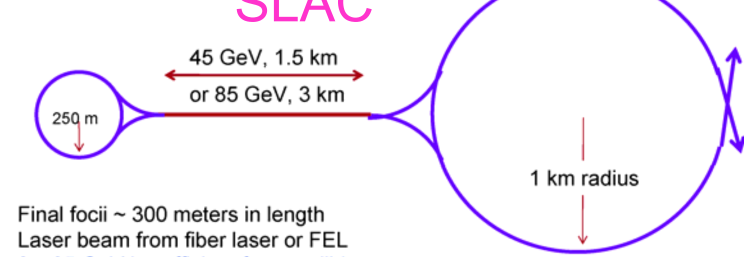
FNAL



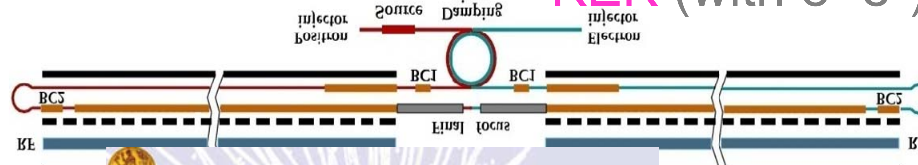
JLAB

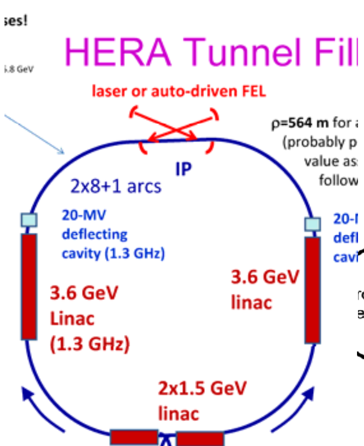
FNAL

SLAC

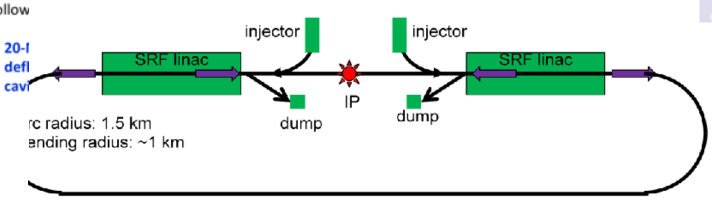


KEK (with e+e-)





JLAB



Turkey

Laser for HFiTT

Fiber Lasers -- Significant breakthrough

Gerard Mourou et al., *"The future is fiber accelerators," Nature Photonics, vol 7, p.258 (April 2013).*

ICAN – International Coherent Amplification Network

Figure 2: Principle of a coherent amplifier network (CAN) based on fiber laser technology. An initial pulse from a seed laser (1) is stretched (2), and split into many fibre channels (3). Each channel is amplified in several stages, with the final stages producing pulses of ~1 mJ at a high repetition rate (4). All the channels are combined coherently, compressed (5) and focused (6) to produce a pulse with an energy of >10 J at a repetition rate of 10 kHz (7). [3]

10 J, 10 kHz

Very good approach for equal spacing between bunches and problematic for collider with bunch trains, such as ILC, CLIC, because need very high diode peak power.

Plasma people also like photon colliders, because acceleration of electron is easier than positrons

Schroeder er al., PRST (2010)

TABLE II. Example parameters for a 0.5 TeV laser-plasma linear $\gamma\gamma$ collider.

Plasma number density, n_0 [cm^{-3}]	10^{17}
Beam energy, γmc^2 [TeV]	0.25
Geometric luminosity, $\mathcal{L}$ [10^{34} s^{-1} cm^{-2}]	2
Number per bunch, N [10^9]	4
Collision frequency, f [kHz]	15
Number of stages (1 linac), N_{stages}	25
Linac length (1 beam), L_{total} [km]	0.05
Total wall-plug power, P_{wall} [MW]	80
Compton scattering laser wavelength [μm]	1
Compton scattering laser energy [J]	6
Compton scattering laser duration [ps]	7
Compton scattering laser Rayleigh range [mm]	1
Compton scattering intensity [10^{18} W/cm^{-2}]	0.27
Gamma beam peak energy [TeV]	0.2
Conversion efficiency [$e \rightarrow \gamma$]	0.65

If not ILC, other people will do γγ collider someday.

Physics motivation for the photon collider at LC
(shortly, independent on a physics scenario)

In $\gamma\gamma$, γe collisions compared to e^+e^-

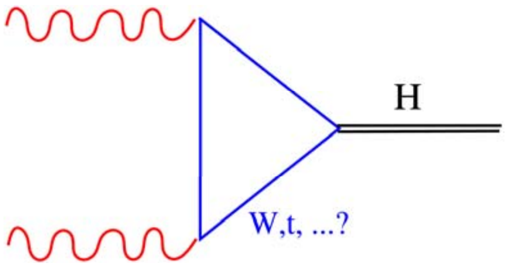
- the energy is smaller only by 10-20%
- the number of interesting events is similar or even higher
- access to higher particle masses (H,A in $\gamma\gamma$, charged and light neutral SUSY in γe)
- higher precision for some phenomena ($\Gamma_{\gamma\gamma}$, CP-proper.)

  $\Gamma(H\to\gamma\gamma)$ width can be measured with statistics ≈ 60 times higher than in e+e- collisions.
- different types of reactions (different dependence on theoretical parameters)

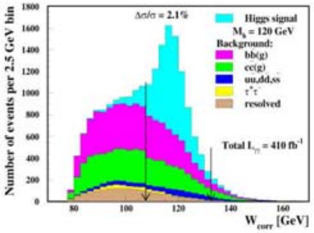
It is the unique case when linear colliders allow to study new physics in several types of collisions at the cost of very small additional investments

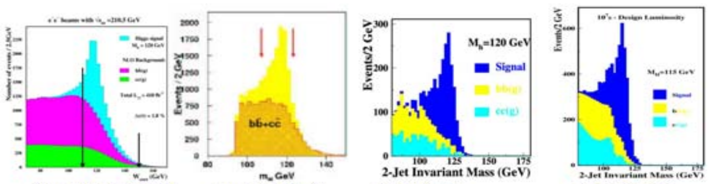
Unfortunately, the physics in LC region is not so rich as expected, by now LHC found only light Higgs boson.

The resonance Higgs production is one of the gold-plated processes for PLC



Very sensitive to high mass particles in the loop





Niezurawski(TESLA) Rosca(TESLA) Asner(NLC) Asner(Cliche)

$$\dot{N}_H = L_{ee} \times \frac{dL_{0,\gamma\gamma}}{dW_{\gamma\gamma} L_{ee}} \frac{4\pi^2 \Gamma_{\gamma\gamma}}{M_H^2} (1 + \lambda_1\lambda_2 + CP * l_1 l_2 cos2\varphi) = L_{ee}\sigma$$

$$\sigma = \frac{0.98 \cdot 10^{-35}}{2E_0[\mathrm{GeV}]} \frac{dL_{0,\gamma\gamma}}{dz L_{ee}} (1 + \lambda_1\lambda_2 + CP * l_1 l_2 cos2\varphi), \ \mathrm{cm}$$

For realistic ILC conditions $\sigma(\gamma\gamma\to H)\approx 75$ fb, while $\sigma(e^+e^-\to HZ)\approx 290$ fb

in e+e- $N(H\to\gamma\gamma)\infty$ L $\sigma(e^+e^-\to HZ)*Br(H\to\gamma\gamma)$, where $Br(H\to\gamma\gamma)=0.0024$

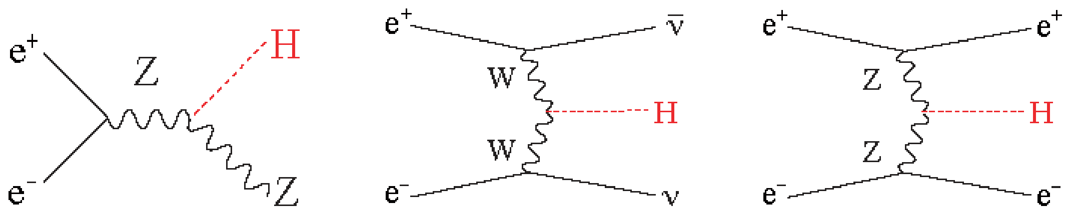
in $\gamma\gamma$ $N(H\to\gamma\gamma)\infty$ L $\sigma(\gamma\gamma\to H)*Br(H\to bb)$, where $Br(H\to bb)=0.57$

Conclusion: in γγ collisions the $\Gamma(H\to\gamma\gamma)$ width can be measured with statistics (75*0.57)/(290*0.0024)=60 times higher statistics than in e+e- collisions. That is one of important argument for the photon collider.

Remark on Photon collider Higgs factories

Photon collider can measure
$\Gamma(H\to\gamma\gamma)*Br(H\to bb, ZZ, WW)$, $\Gamma^2(H\to\gamma\gamma)/\Gamma_{tot}$, Higgs CP properties (using photon polarizations). In order to get $\Gamma(H\to\gamma\gamma)$ one needs $Br(H\to bb)$ from e+e-(accuracy about 1%). Other Higgs decay channels will be unobservable due to large QED background.

e+e- can also measure $Br(bb, cc, gg, \tau\tau, \mu\mu, \text{invisible})$, Γ_{tot}, less backgrounds due to tagging of Z.



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

In 2009 Hirotaki Sugawara proposed to build $\gamma\gamma$ collider before e+e- (because cheaper), this was not supported.

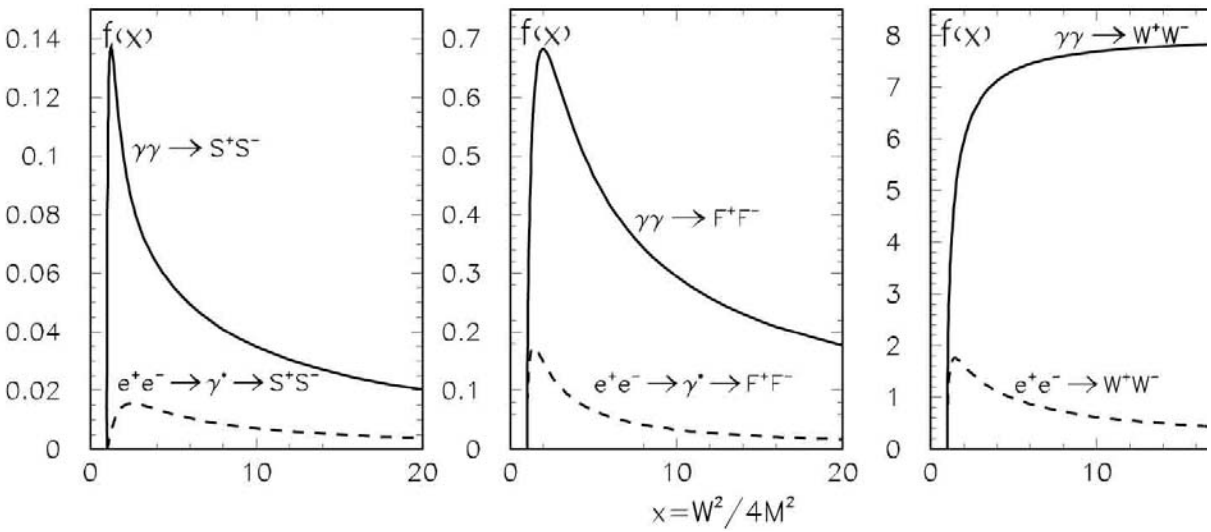
Some examples of Physics (in addition to H(125))

Charged pair production in e^+e^- and $\gamma\gamma$ collisions.

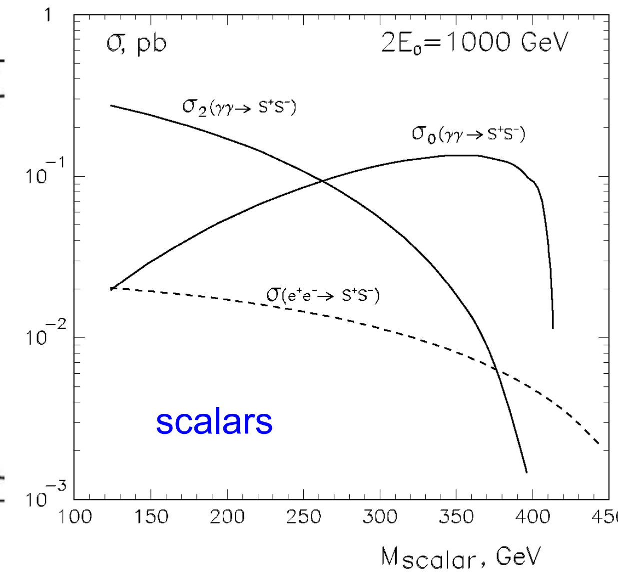
unpolarized beams

(S (scalars), F (fermions), W (W-bosons);

$\sigma = (\pi\alpha^2/M^2)f(x)$, beams unpolarized)



polarized beams



So, typical cross sections for charged pair production in $\gamma\gamma$ collisions is larger than in e^+e^- by one order of magnitude (circular polarizations helps)

Not seen at LHC

Supersymmetry in $\gamma\gamma$

In supersymmetric model there are 5 Higgs bosons:

h^0 light, with $m_h < 130$ GeV

H^0, A^0 heavy Higgs bosons;

H^+, H^- charged bosons.

$M_H \approx M_A$, in e^+e^- collisions H and A are produced in pairs (for certain param. region), while in $\gamma\gamma$ as the single resonances, therefore:

in e^+e^- collisions $M_{H,A}^{max} \sim E_0$ $(e^+e^- \to H + A)$
in $\gamma\gamma$ collisions $M_{H,A}^{max} \sim 1.6E_0$ $(\gamma\gamma \to H(A))$

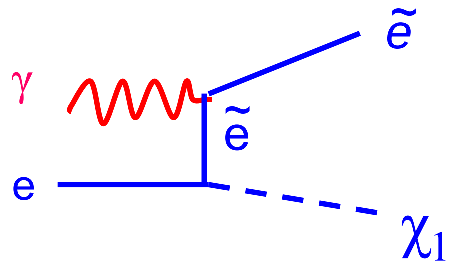
For some SUSY parameters H,A can be seen only in $\gamma\gamma$
(but not in e+e- and LHC)

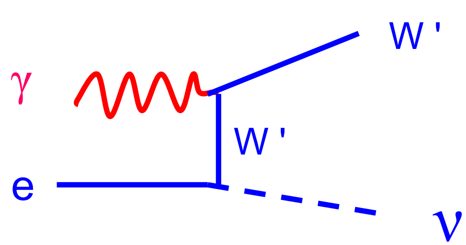
Not seen at LHC

Supersymmetry in γe

At a γe collider charged particles with masses higher than in e^+e^- collisions at the same collider can be produced (a heavy charged particle plus a light neutral one, such as a new W' boson and neutrino or supersymmetric charged particle plus neutralino):

$$m_{\tilde{e}^-} < 0.9 \times 2E_0 - m_{\tilde{\chi}_1^0}$$





Not seen at LHC

Conclusion

- Photon colliders have sense as a very cost effective addition for e+e- linear colliders. Unfortunately, LC was delayed too much, the physics case for $\gamma\gamma$ (after LHC runs) is not so nice as expected, but situation may change unexpectedly, the ILC design should reserve the possibility of $\gamma\gamma$ collider from the very beginning: the crossing angle 25 mrad is needed!
- The $\gamma\gamma$ is very natural at e+e- collider, it is also attractive independently, both at high (very high, plasma, etc) energies or at low energies (see my next talk on $\gamma\gamma$ collider with $W_{\gamma\gamma} \leq 12$ GeV).
- Photon collider is the most outstanding application of lasers for fundamental physics. Such multidisciplinary project may be interesting for many people (and funding agencies). The photon collider is one of ILC advantages over the FCC.