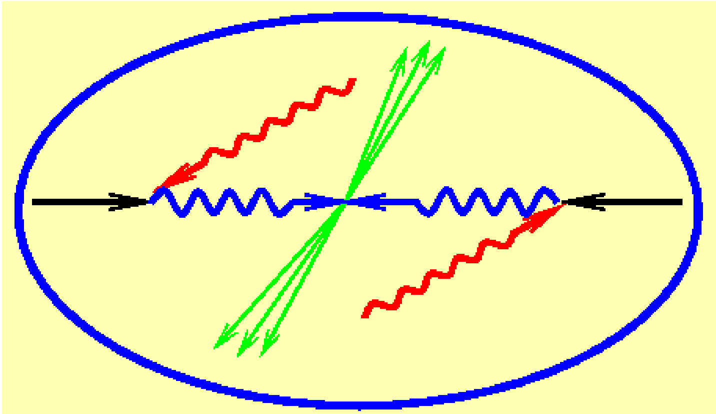


Optimization of the beam crossing angle at the ILC for e^+e^- and $\gamma\gamma$ collisons

Valery Telnov

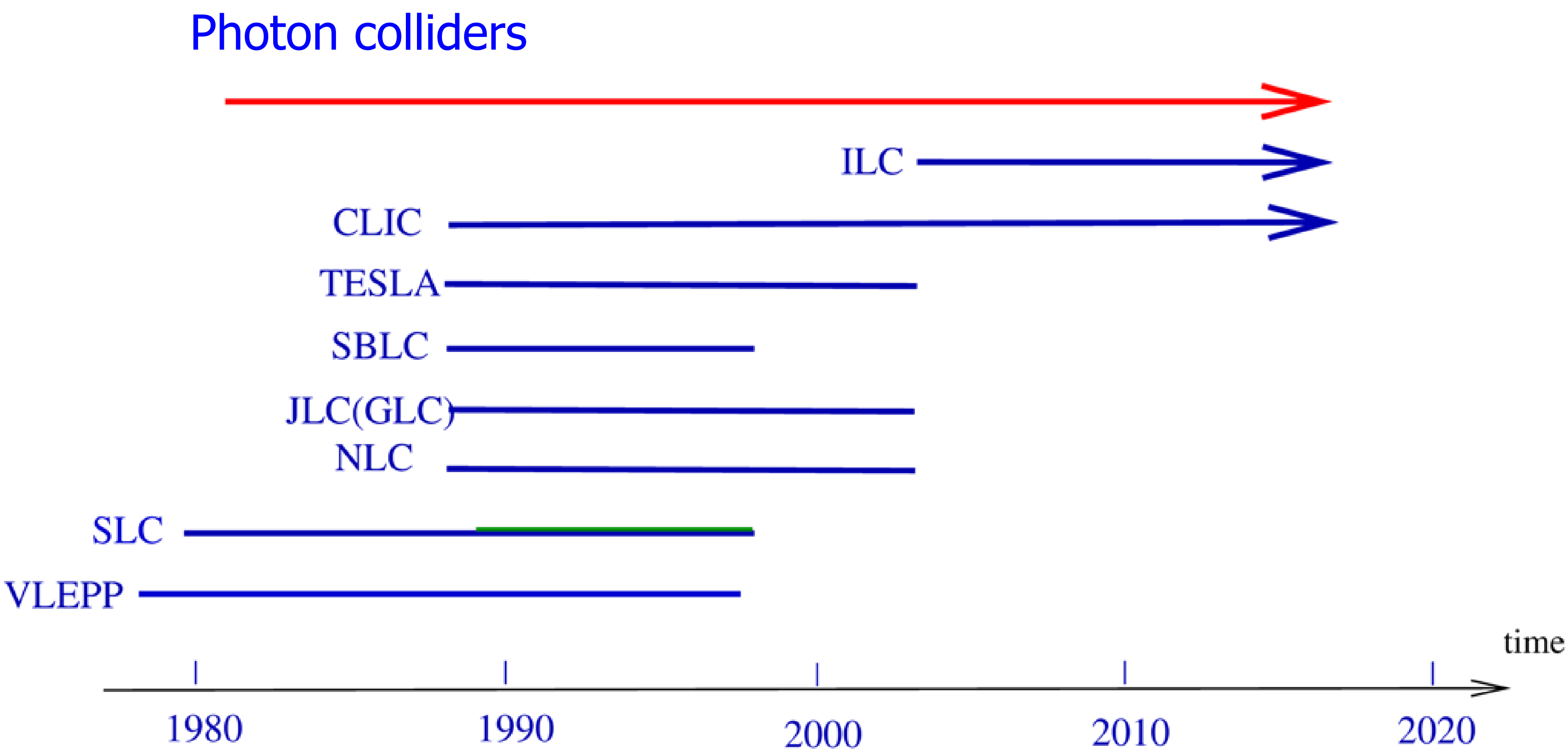
Budker INP and Novosibirsk St. Univ.

INSTR-2017,Novosibirsk, February 27, 2017

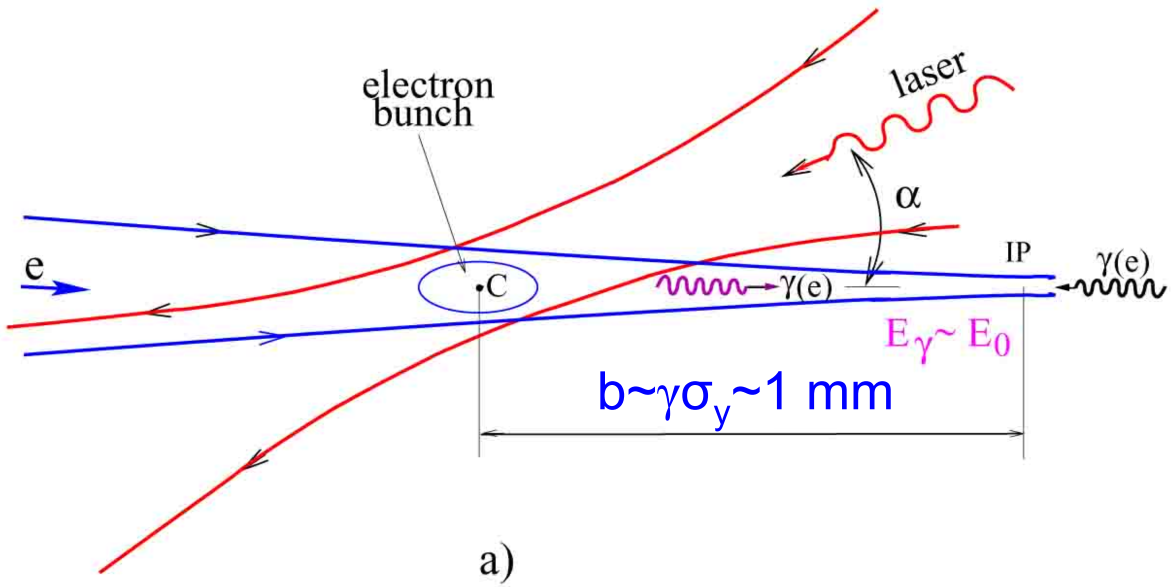
Contents

- Introduction
- The X(750) bump as a "god signal" to remind about the PLC.
- Crossing angle (25 $\rightarrow$ 20 mrad)
- Profits of larger laser wavelength (1 $\rightarrow$ 2 μm)
- Conclusion

Linear colliders (projects)



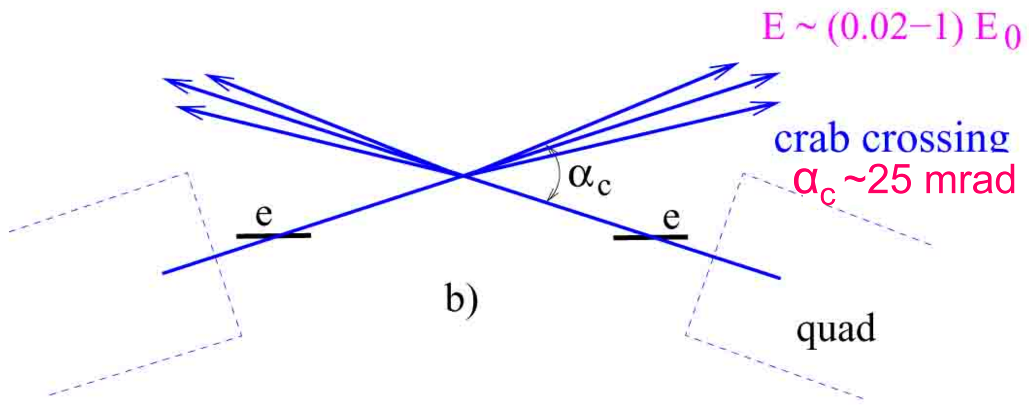
Scheme of $\gamma\gamma$, γe collider



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

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

$E_0 = 250$ GeV, $\omega_0 = 1.17$ eV ($\lambda = 1.06\ \mu$m) $\Rightarrow$ x=4.5, ω_m=0.82E_0=205 GeV

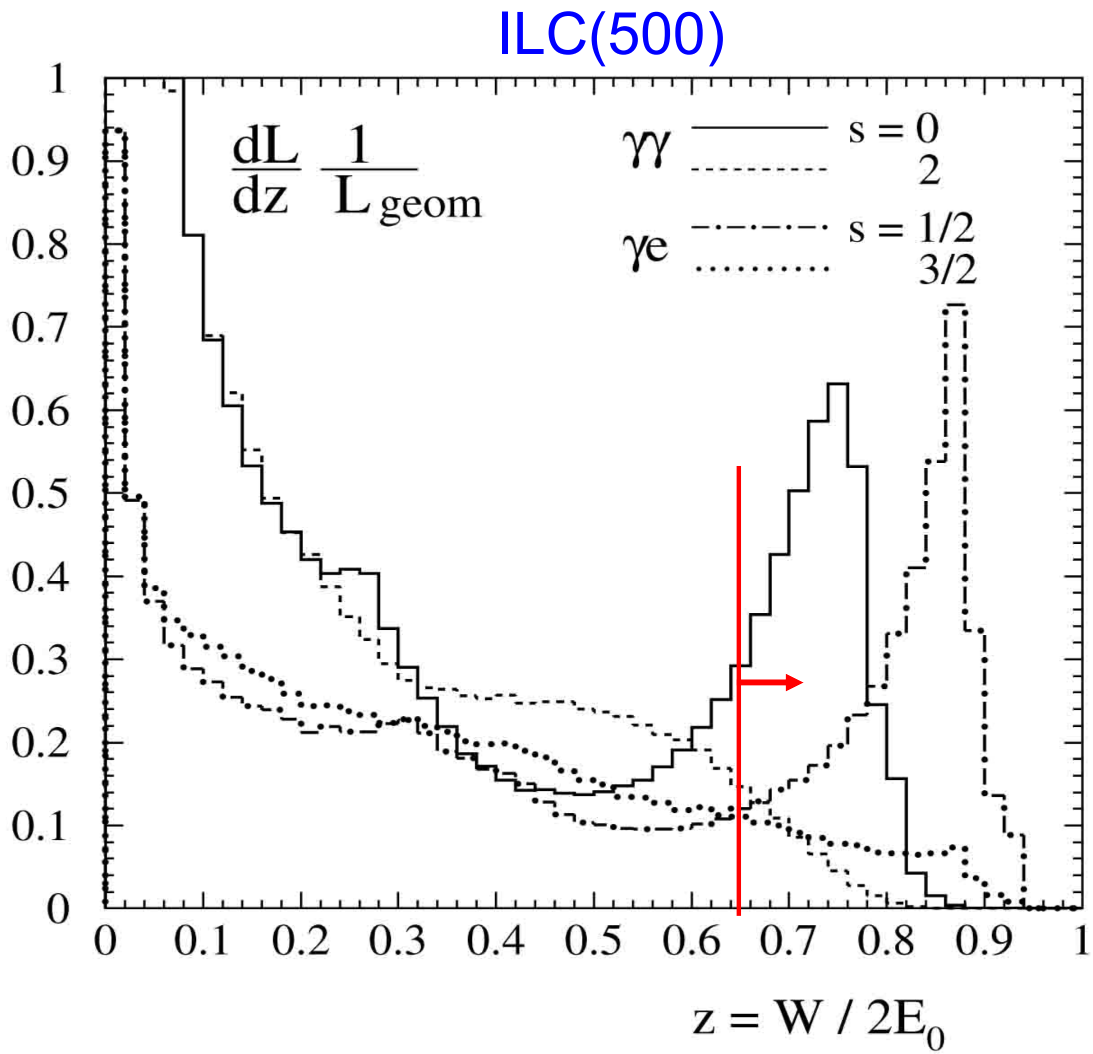


$x = 4.8$ is the threshold for $\gamma\gamma_L \to e^+e^-$ at conv. reg.

ω_{max}~0.8 E_0

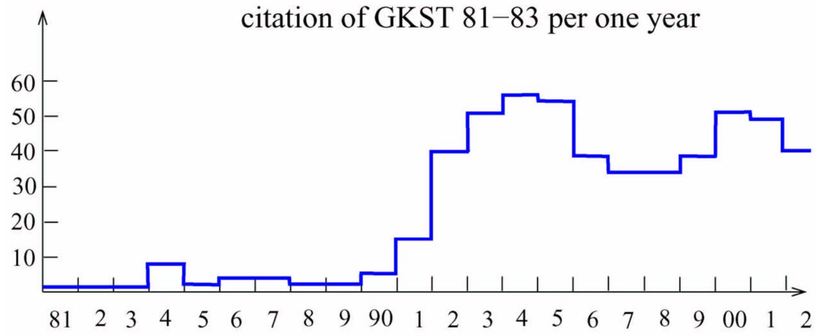
$W_{\gamma\gamma,\ max} \sim 0.8 \cdot 2E_0$
$W_{\gamma e,\ max} \sim 0.9 \cdot 2E_0$

Typical $\gamma\gamma$, γe luminosity spectra



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

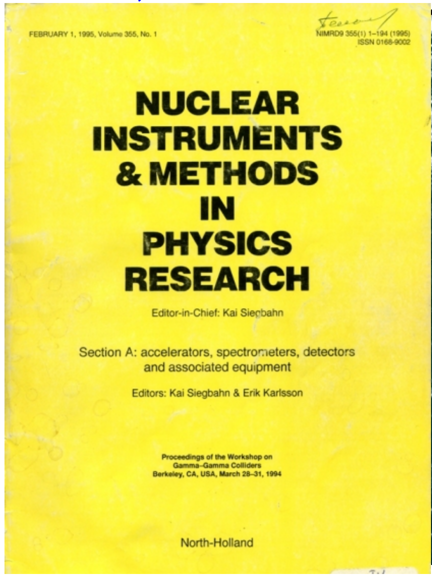
Activity on photon colliders



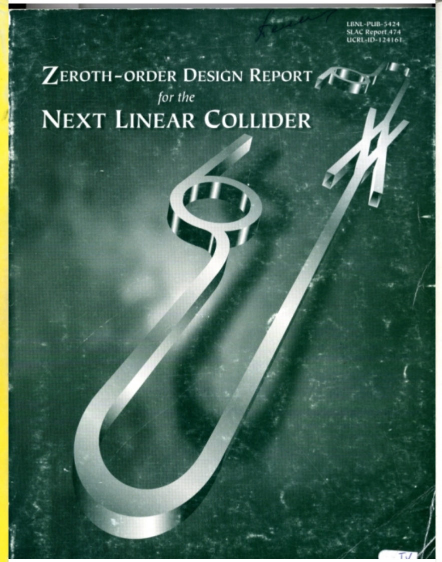
(total number of publications is larger by a factor of 2)

$\longrightarrow$ about 2 papers/week

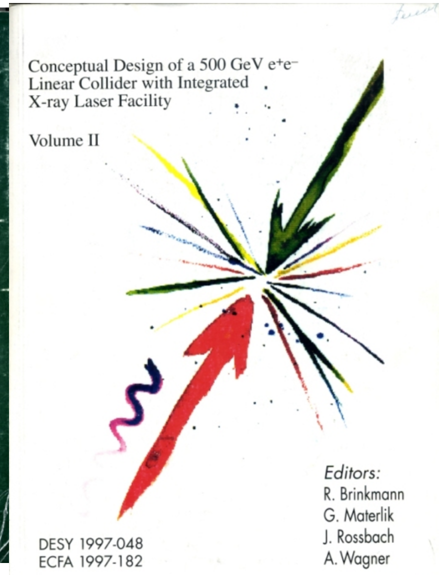
Gamma-gamma workshop LBL, 1994



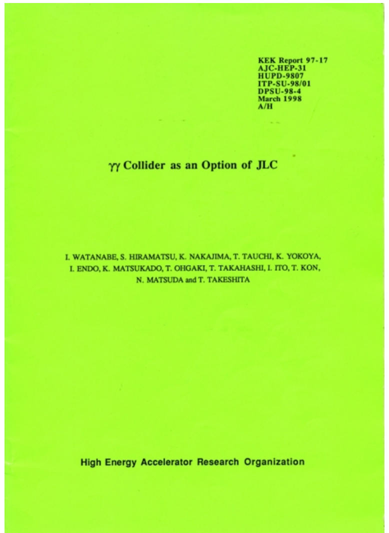
NLC



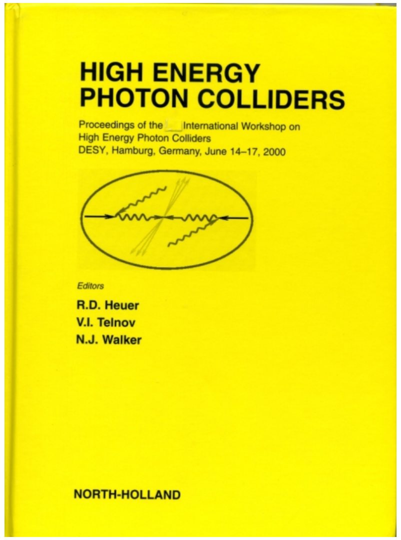
TESLA CDR



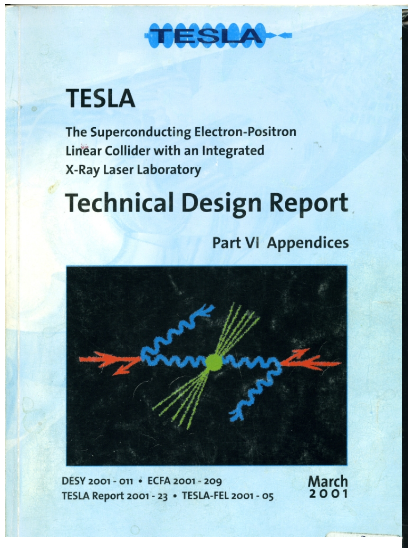
γγ at JLC



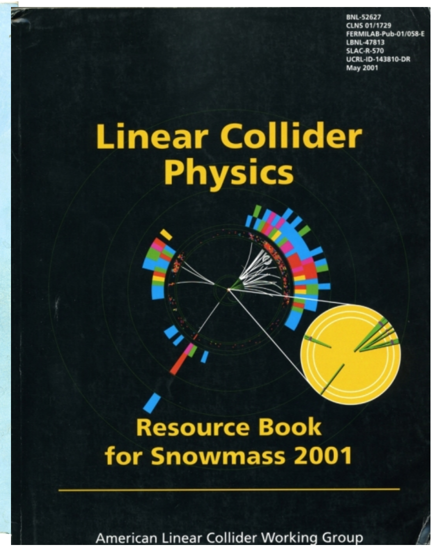
γγ at DESY



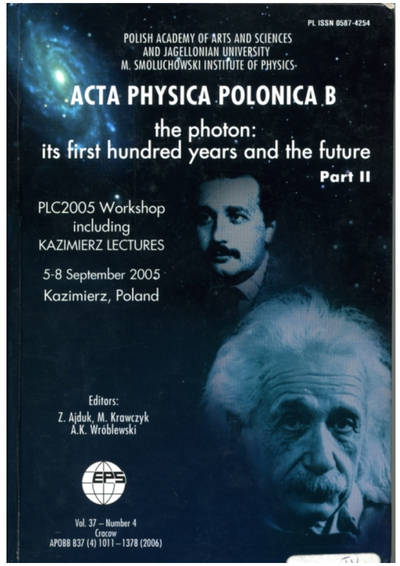
TESLA TDR



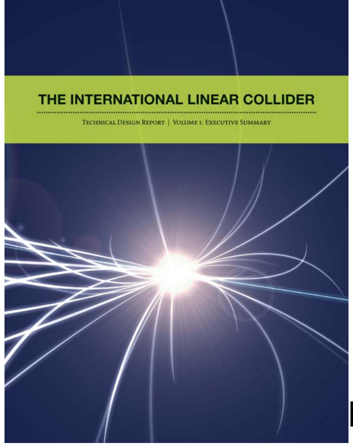
γγ NLC



PLC 2005

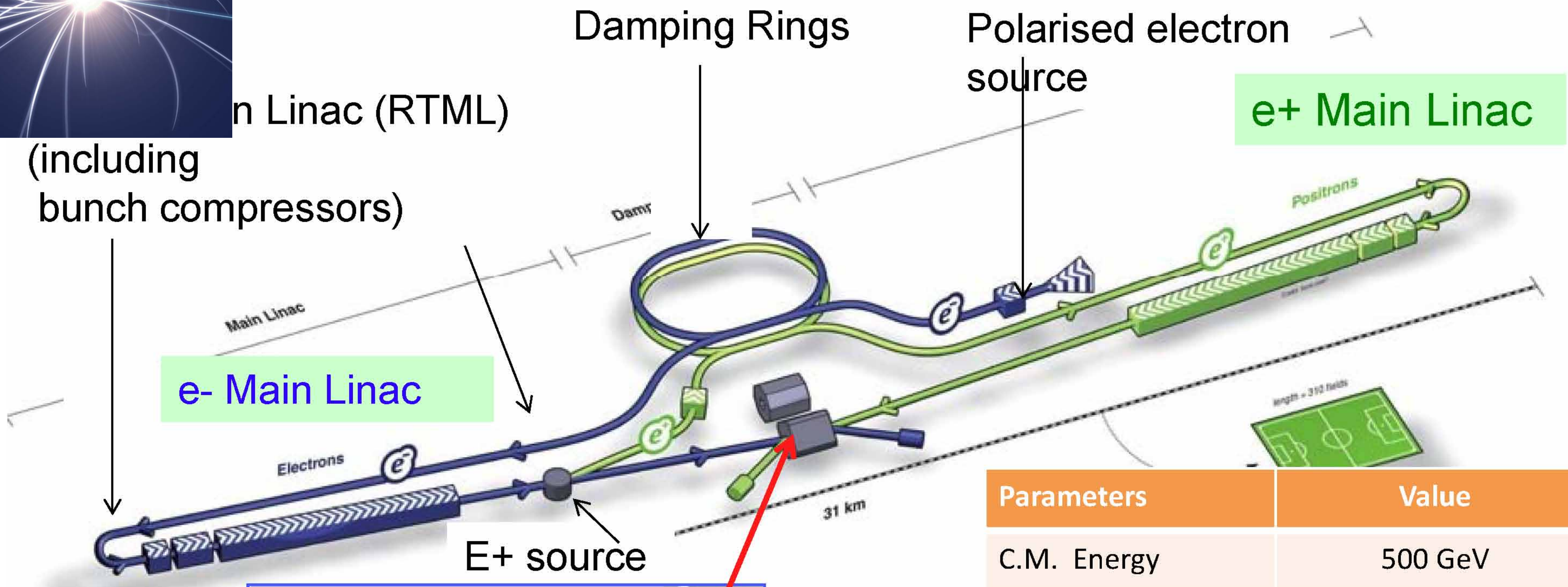


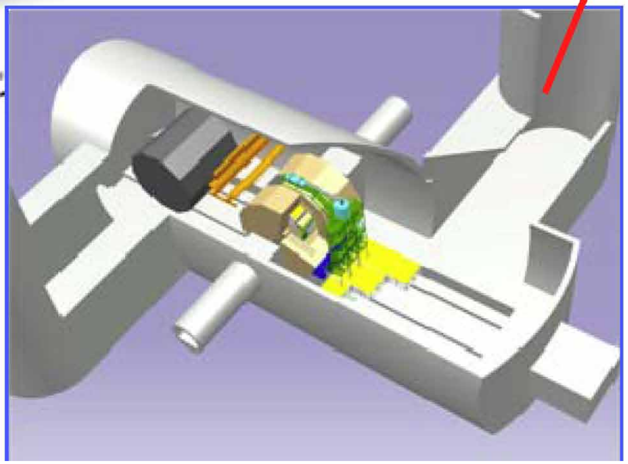
Photon colliders were suggested in 1981 and since ~1990 are considered as a natural part of all linear collider projects.



ILC TDR
6.2013

ILC TDR Layout

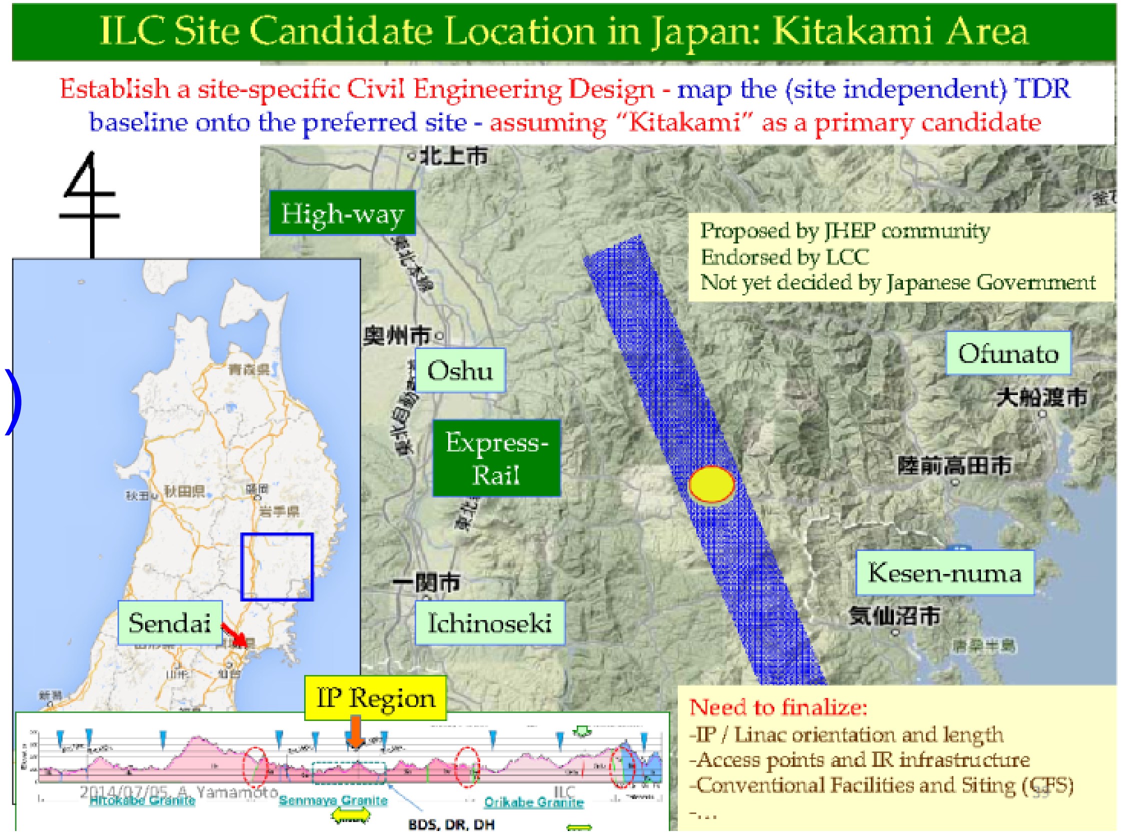


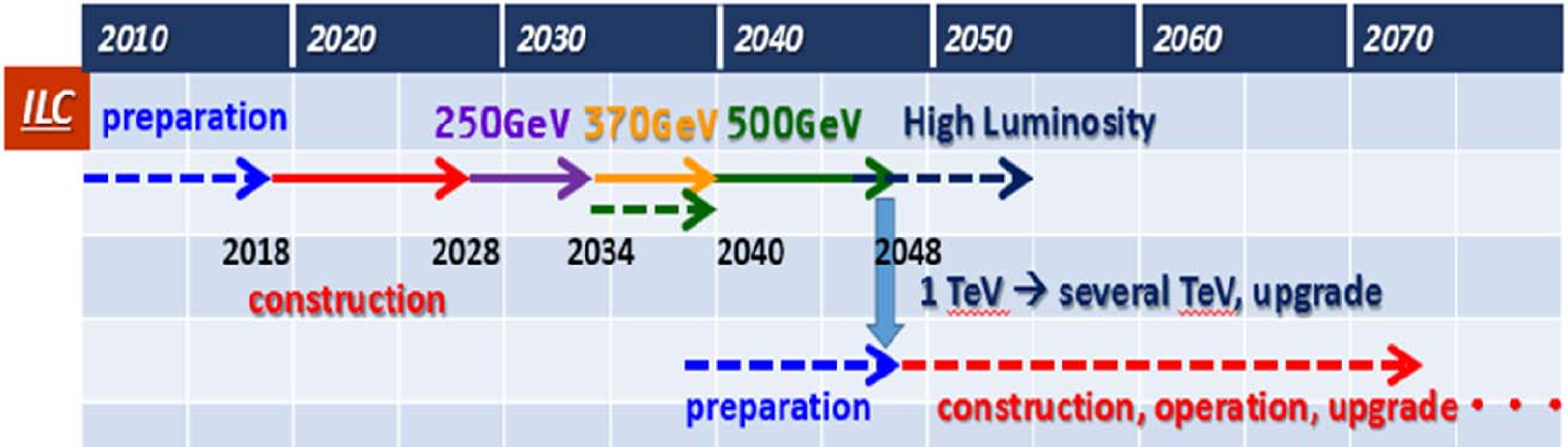


Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
E gradient in SCRF acc. cavity	31.5 MV/m +/-20% Q_0 = 1E10

2E=250-500 GeV, upgradable to 1000 GeV

Japan is interested to host
-decision ~2018
-construction ~2019 (~10 years)
-physics ~2030

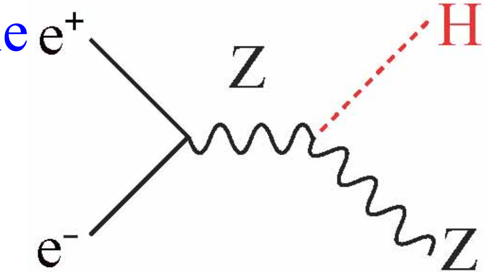




Known physics, ILC stages

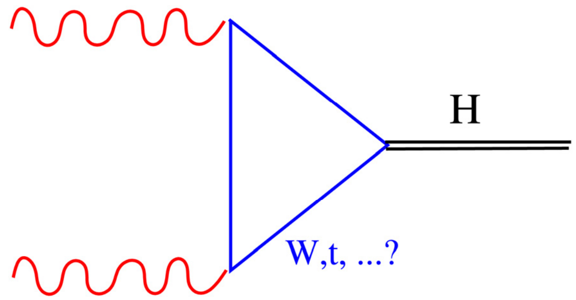
In e+e-

- 2E=250 GeV Higgs boson, Br(bb, cc, gg, ττ, μμ, invisible
  Γtot, Z tagging
- 350 top quark
- 500 ZHH –Higgs self coupling
- 500 and higher ttH - top Yukawa coupling
- 1000 and higher Beyond



In γγ

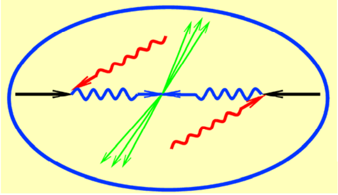
$\Gamma_{\gamma\gamma}(H)$ is determited by contributions of all charge particles (even with $M>2E_0$), therefore this process is most sensitive to new physics!



In γγ collisions the Γ(H→γγ) width can be measured with statistics ≈ 90 times higher than in e+e- collisions. This is the most important argument for the photon collider .

However, e+e- beams are much better for Higgs study (due to Z tagging). Therefore PLC has sense only in combination with e+e-: parallel work or second stage.

Photon collider in ILC project



ILC uses the same technology as TESLA which published TDR in 2001, all new developments were focused on the cost reduction: only one IP, only e+e- in the baseline project.

There was suggestion (Sugawara) in 2009 to build PLC for the Higgs study before e+e-, but it was not supported because e+e- are much better for H study.

So, the PLC is considered as an option which will be realized either after finishing e+e- program (in >20 years) or earlier, if strong physics case.

It is OK, there is only one problem for now:
the ILC design should be compatible with the PLC in order to have possibility of PLC in the future.

The most important requirement: the crossing angle should be about 25 mrad for PLC, while it is now 14 mrad for e+e-.

This problem is well known but not solved yet because the most important problem for the ILC management is the approval of the ILC project in the present baseline (cheapest) version.

However, in 2015 the HEP community was excited by the unexpected diphoton signal of new physics at LHC, which was the best possible argument for the photon collider.

X(750)

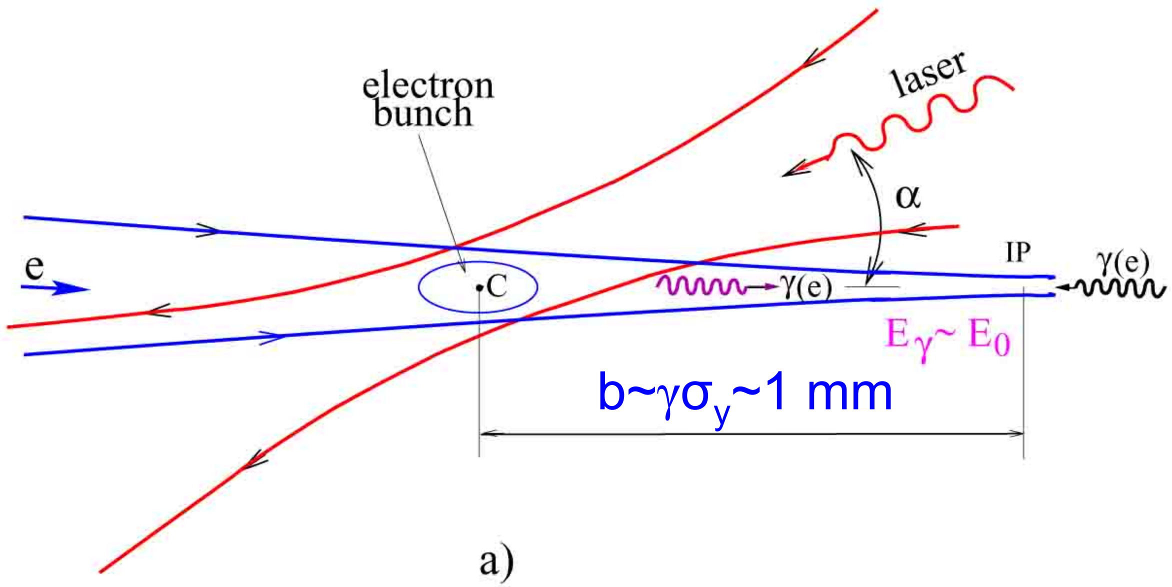
In 2015 two detector at LHC have observed the (fake) diphoton peak at $W_{\gamma\gamma} \approx 750$ GeV which caused a lot of excitement in HEP community (> 500 papers).

On June 9 Lyn Evans has written in LC Newsline:
"On the scientific side, there was much discussion of the possible sighting of a new resonance at 750 GeV at the LHC and its implications for the ILC. If this resonance is confirmed in the coming months, it is recommended that the possible option of running the ILC as a gamma-gamma collider at 1 TeV as well as an e+e–collider be strongly pursued. This would require a minor modification of the ILC layout."

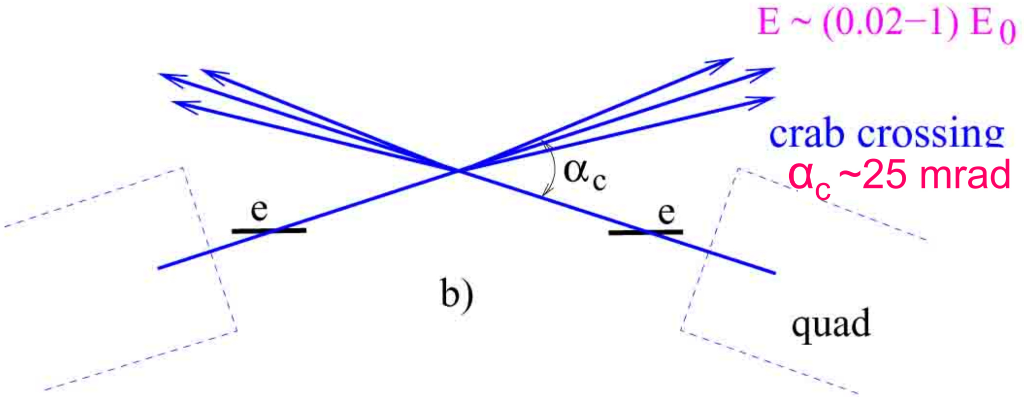
Yes, now it requires minor modification, but if to do nothing, later such modification (crossing angle) will be very difficult.

The god likes to speak with people indirectly and this diphoton bump was just a gentle reminding to the LCC and LCB that it is time to correct the ILC design in order to make it compatible with the photon collider.

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
($\lambda = 1.06\ \mu$m) $\Rightarrow$
x=4.5, ω_m=0.82E_0=205 GeV

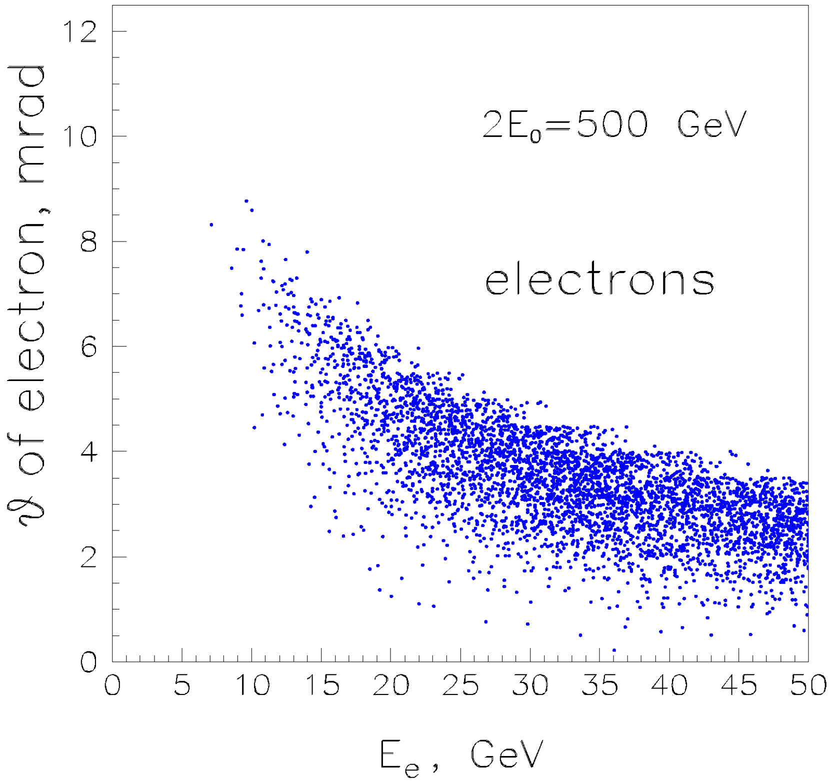
$x = 4.8$ is the threshold for
$\gamma\gamma_L \to e^+e^-$ at conv. reg.

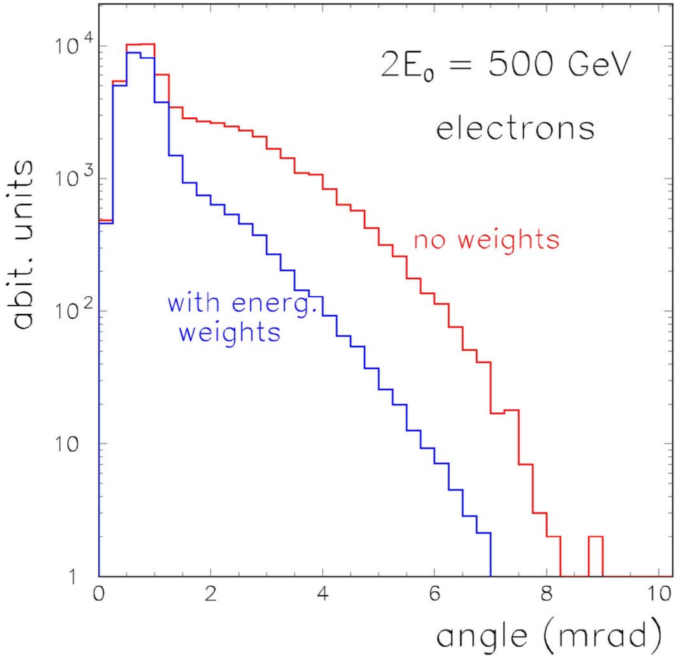
ω_{max}~0.8 E_0

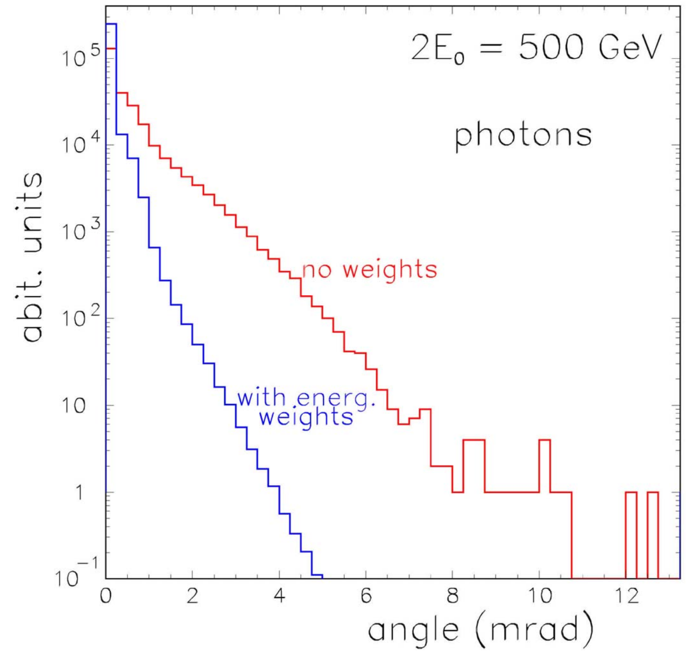
$W_{\gamma\gamma,\ max}$ ~ 0.8·2E_0
$W_{\gamma e,\ max}$ ~ 0.9·2E_0

Properties of the beams after CP,IP

Angles of disrupted electrons after Compton scattering and interaction with opposing electron beam; $N=2\cdot10^{10}$, σ_z =0.3 mm



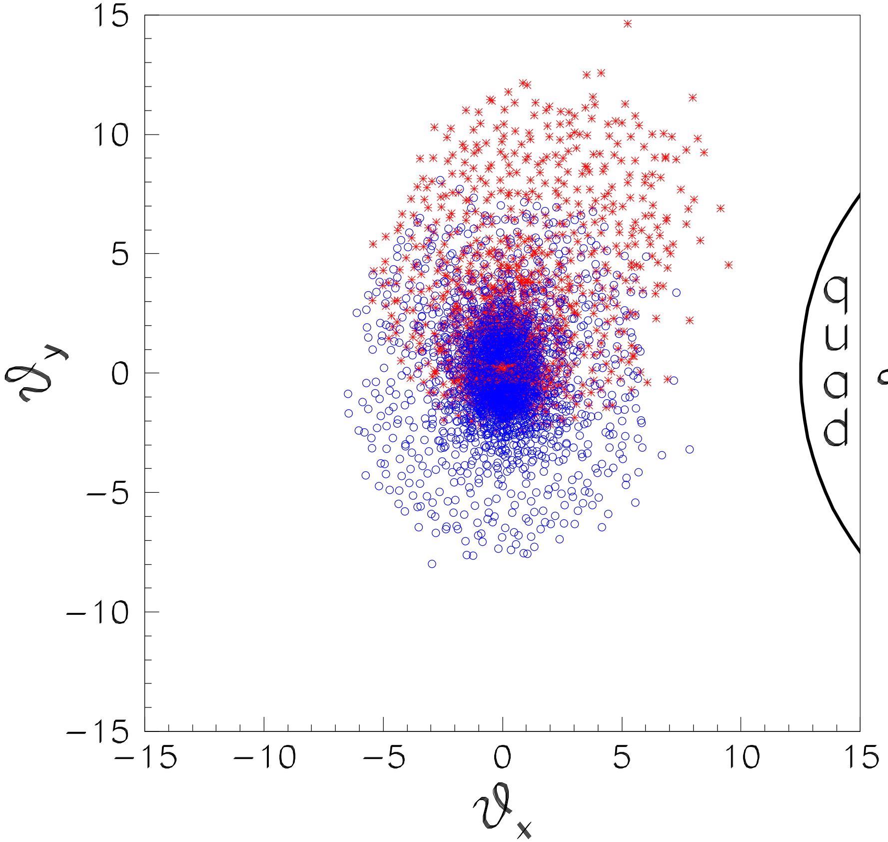




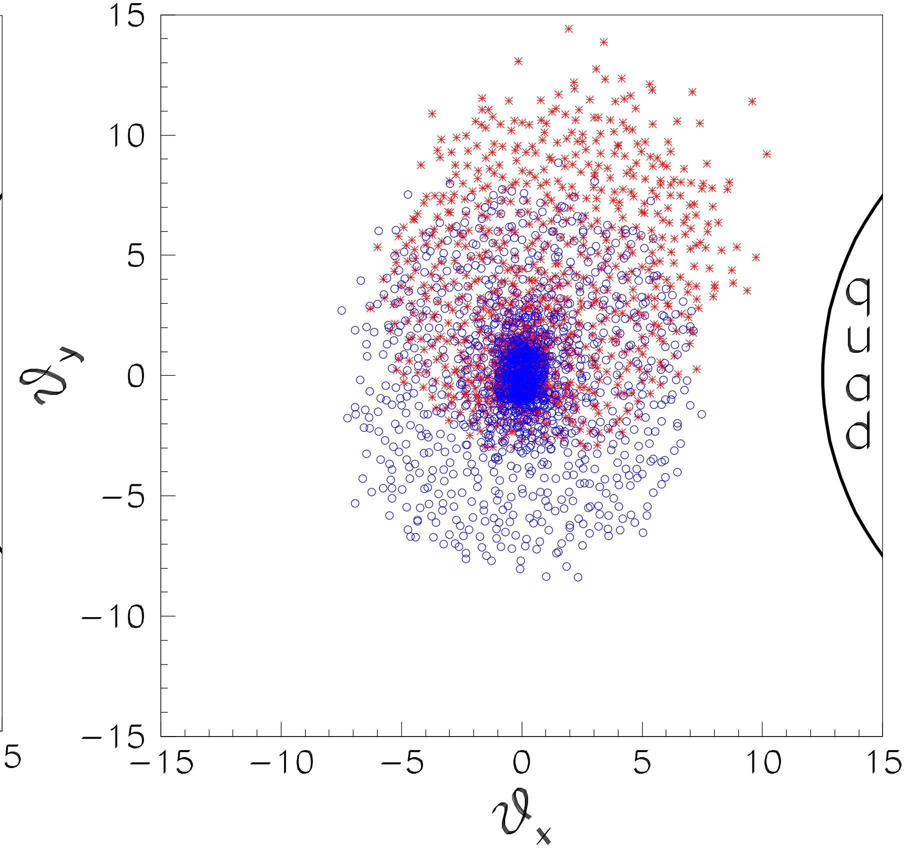
Low energy electron are deflected in the field of the opposing e-beam

The additional deflection ~2-4 mrad adds the detector field

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



$2E_0$=200 GeV



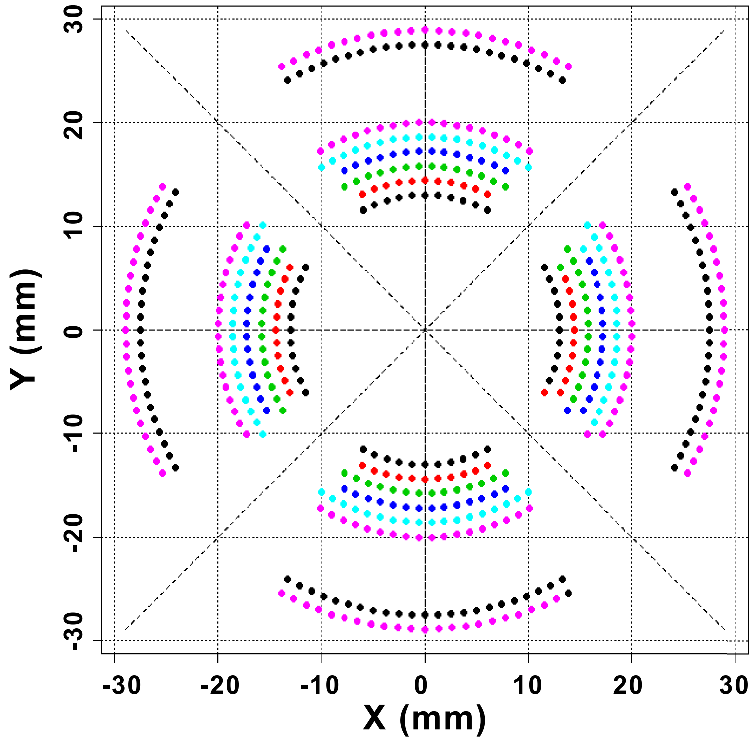
$2E_0$=500 GeV

With account of tails the save beam sizes are larger by about 20 %.

So, for $N=2\cdot10^{10}$, $x\approx4.8$, $p=1$ and $\lambda=1$ μm

$E_{min}\approx5$ GeV and $\theta_d\approx10$-12 mrad

Principle design of the superconducting quad (B.Parker), only coils are shown (two quads with opposite direction of the field inside each other). The radius of the quad with the cryostat is about 5 cm.



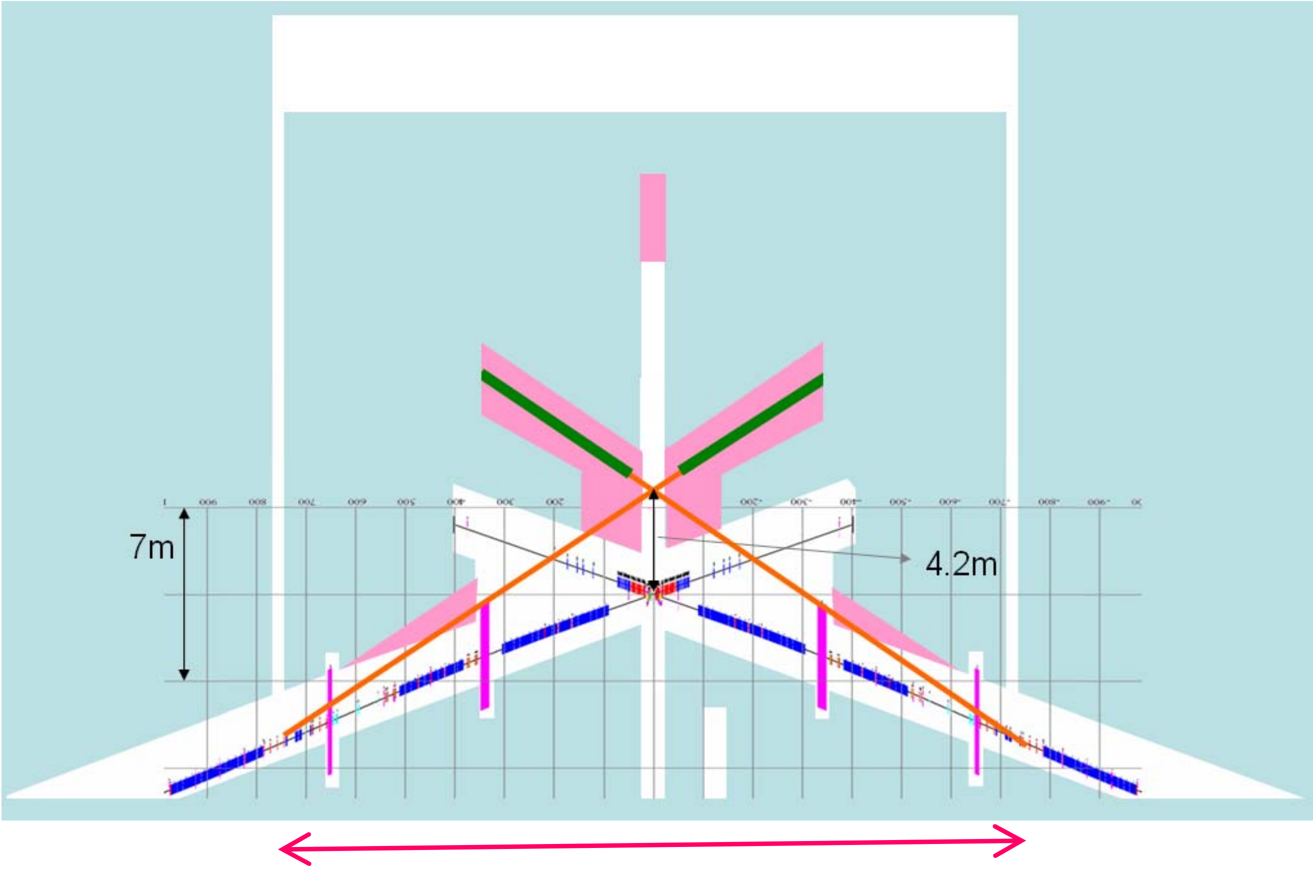
(At present warm hybrid quads are considered as well)

$$\alpha_c = (5/400)*1000(\text{quad}) + 12.5(\text{beam}) \sim 25 \text{ mrad}$$

So, the required crossing andle for PLC is about 25 mrad

It is larger than in e+e- case (14 mrad) due to disruption angles and lower energies.

14mr => 25mr Old scheme A.Seryi, LCWS06



additional angle is 5.5mrad and detector needs to be moved by about 4.2m as well as 1.4 km of beam lines + separate beam dump, too big job!

Much more attractive would be the same angle for e+e- and $\gamma\gamma$.

Influence of SR in the solenoid field on luminosity

as a function of the crossing angle (full simulation)

(V.Telnov, physics/0507134)

Results on $L(\alpha_c)/L(0)$.

e^+e^- collisions

α_c(mrad)	0	20	25	30	35	40
LDC(TESLA)	1.	0.98	0.95	0.88	0.83	0.76
SID	1.	0.995	0.985	0.98	0.95	0.91
GLD	1.	0.995	0.98	0.97	0.94	0.925

$\gamma\gamma$ collisions

α_c(mrad)	0	20	25	30	35	40
LDC(TESLA)	1	0.99	0.96	0.925	0.86	0.79
SID	1	0.99	0.975	0.955	0.91	0.86
GLD	1	0.995	0.985	0.98	0.97	0.93

At 25 mrad the loss of luminosity is less than 5% and at 20 mrad the effect is negligible. This effect strongly depends on crossing angle $\Delta\varepsilon \sim (B\alpha_c)^5$

The crossing angle somewhat smaller than 25 mrad would be OK both for ILC(e+e-) and PLC.

The maximum disruption angle

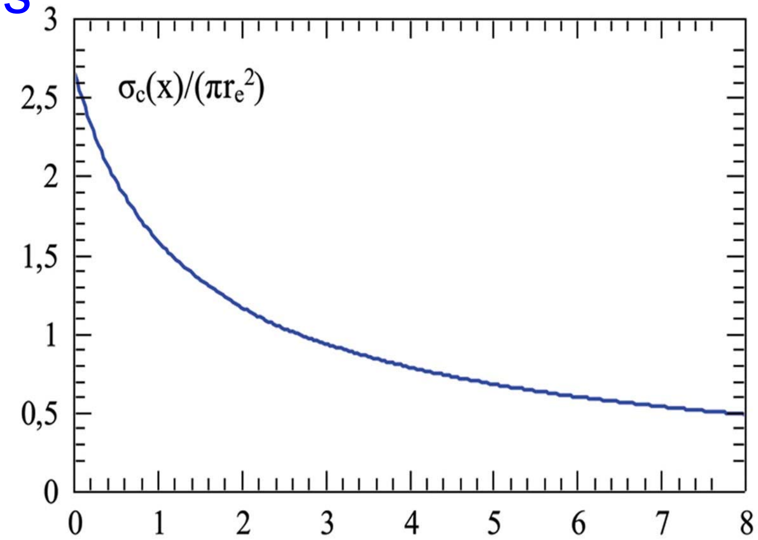
The collision probability at the CP is $p \sim t/\lambda_{sc}$, where $\lambda_{sc} \approx 1/n_\gamma \sigma_c$

After the first scattering the Compton cross section increases from $\sigma_c(x)$ up to $\sigma_T = \frac{8}{3}\pi r_e^2$ and the number of multiple scattering $n \propto \frac{p\sigma_T}{\sigma_c(x)}$

The minimum energy after n Compton scatterings

$$E_{\min} = \frac{E_0}{nx+1} \approx \frac{E_0}{nx} = \frac{m^2c^4}{4\omega_0 n} \sim \frac{m^2c^4\sigma_c(x)}{4\omega_0\sigma_T p}$$

Compton cross section



$$x = \frac{4E_0\omega_0}{m^2c^4}$$

So, for the fixed collision probability (p) and laser wavelength the minimum E_{min} is reached at the maximum collider energy (because σ_c is smaller for larger x, see Fig).

Low energy electrons after multiple Compton scattering are deflected by opposing electron beam, the disruption angle

$$\theta_d \propto \sqrt{N/\sigma_z E_{\min}} \propto \sqrt{Np\omega_0/\sigma_c(x)\sigma_z}$$

The maximum disruption angle (cont.)

So, the disruption angle $\theta_d \propto \sqrt{N/\sigma_z E_{\min}} \propto \sqrt{Np/\sigma_z} \cdot \sqrt{\omega_0/\sigma_c(x)}$ depends on laser wavelength

while the luminosity $$L \propto k^2 \frac{N^2 f}{\sigma_x \sigma_y} \propto \frac{(1-e^{-p})^2}{\sqrt{\sigma_z}} \propto \frac{p^{1.15}}{\sqrt{\sigma_z}}$$ (for p~1)

(because $k \approx 1-e^{-p}$, $p \approx 1$, and $\sigma_y \propto \sqrt{\varepsilon_y \beta_y} \propto \sqrt{\sigma_z}$)

Ways to 20 mrad from present 25 mrad. In the case of α_c=25 mrad ½ is determined by quad's sizes and ½ by the disruption angle. In order to reduce α_c from 25 to 20 mrad we have to reduce θ_d by 5 mrad or 12.5/7.5=1.67 times.

For the fixed laser wavelength λ=1 μm one can

1) decrease p by a factor of (1.67)2=2.8, from p=1 to 0.358, then the luminosity drops by a factor of 4.4 which is not acceptable.
2) increase σ_z 2.8 times, which leads to the decrease of L by a factor of 1.7, and requires approximately 3 time larger laser flash energy.

Another way is the increase of the laser wavelength! In this way one can reduce the disruption angle without any decrease of the luminosity.

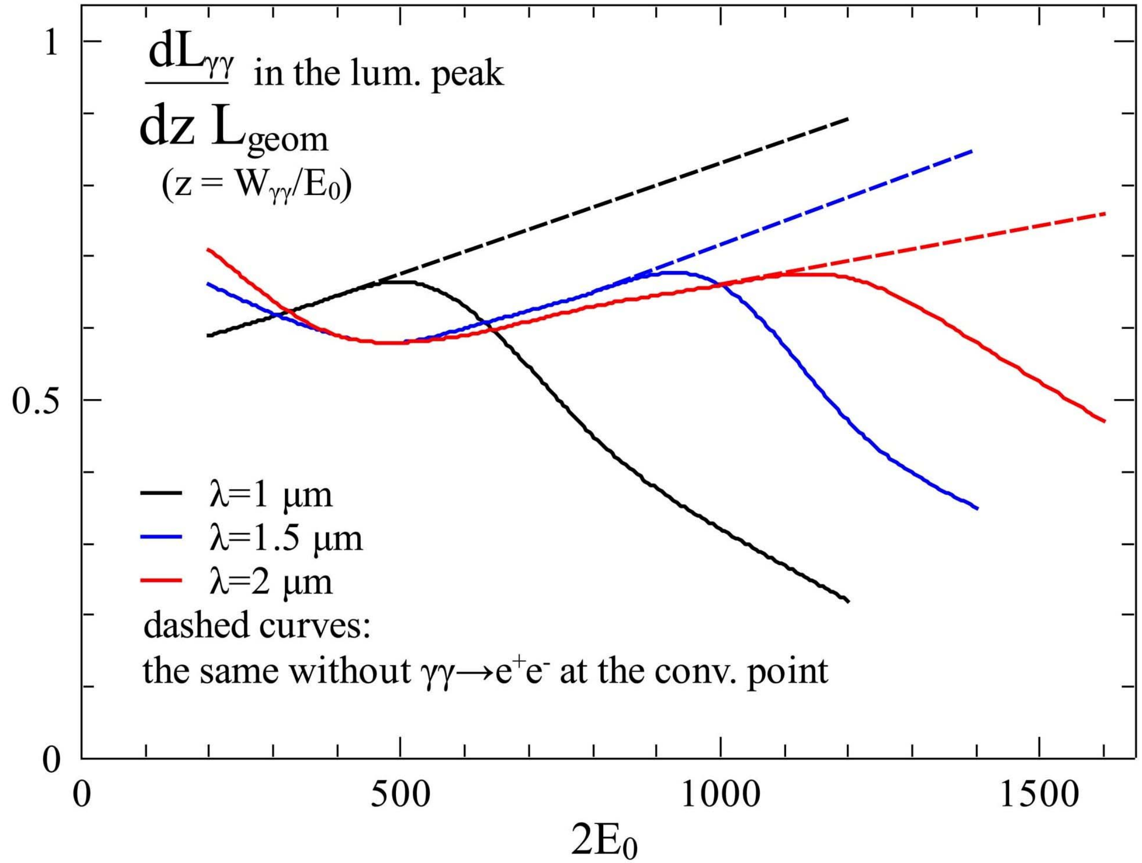
The optimum wavelength for the ILC and dependence of the disruption angle on λ.

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

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

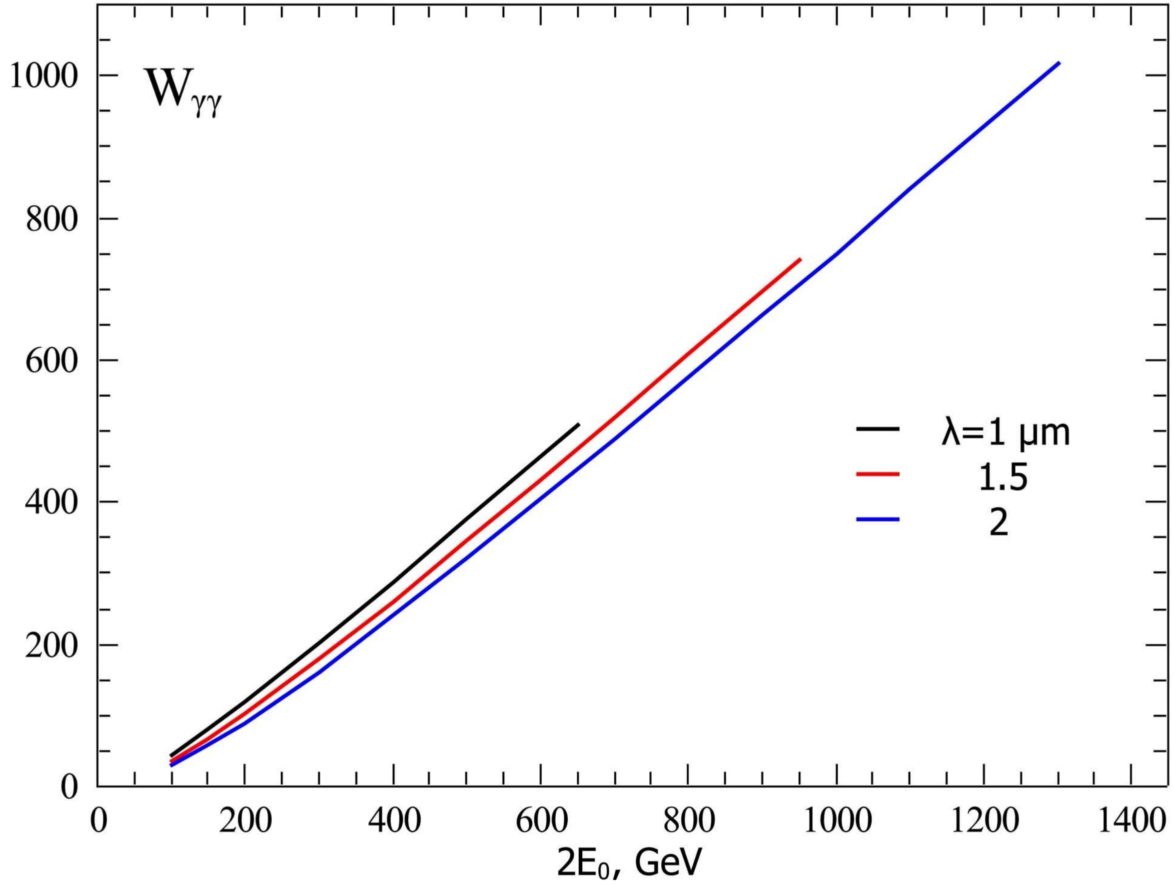


So, λ=1 μm is good only for $2E_0$<500-600 GeV, while the updated ILC energy could reach $2E_0$=1 TeV or even higher.

If the PLC starts operation when ILC already has $2E_0$=1 TeV, the it has big sense to consider λ=2 μm from the very beginning.

This choice has many other advantages, see below.

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).

Disruption angle: 1 μm vs 2 μm

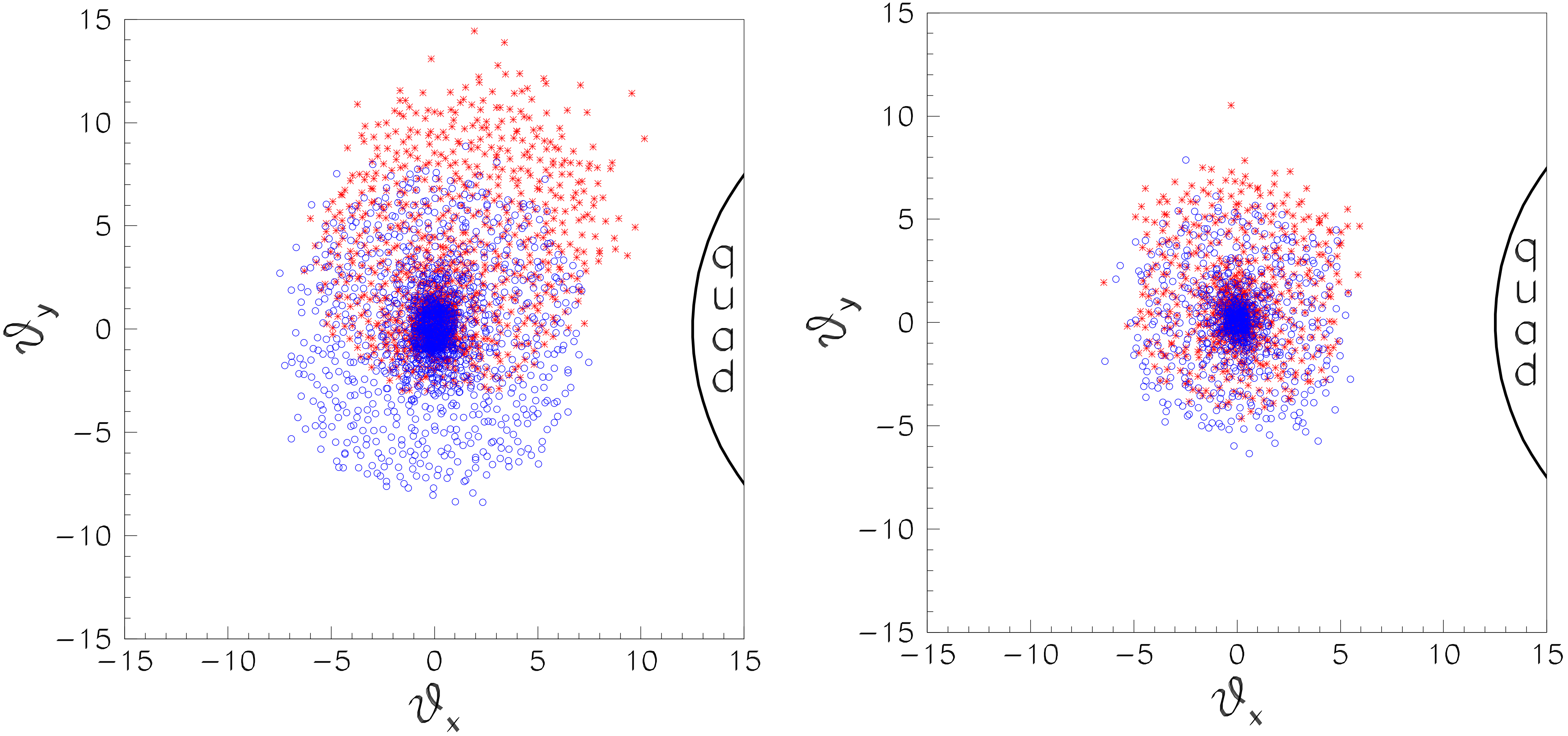
$$\theta_d \propto \sqrt{Np/\sigma_z} \cdot \sqrt{\omega_0/\sigma_c(x)}$$

For $2E_0$=500 and λ=1 μm x=4.75 and σ_c/σ_0=0.705
For $2E_0$=500 and λ=2 μm x=2.37 and σ_c/σ_0=1.1
therefore the disruption angle with λ=2 μm is smaller by a factor of 1.77
(we needed 1.67 in order to reach α_c=20 mrad.)

For $2E_0$=1000 and λ=2 μm x=4.75 and σ_c/σ_0=0.705
and θ_d will be $\sqrt{2}$=1.41 times smaller than for $2E_0$=500 and λ=1 μm (the worst case with θ_d=12.5 mrad).

The factor 1.41 is somewhat smaller than needed 1.77, but present 12.5 mrad has two contributions:
a) from beam-beam collisions which is proportional to 1/sqrt(E_{min})
b) deflection in the solenoid field which is proportional to 1/E_{min}.
so, the decrease θ_d by a factor of $\sqrt{2}$ may be sufficient.

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



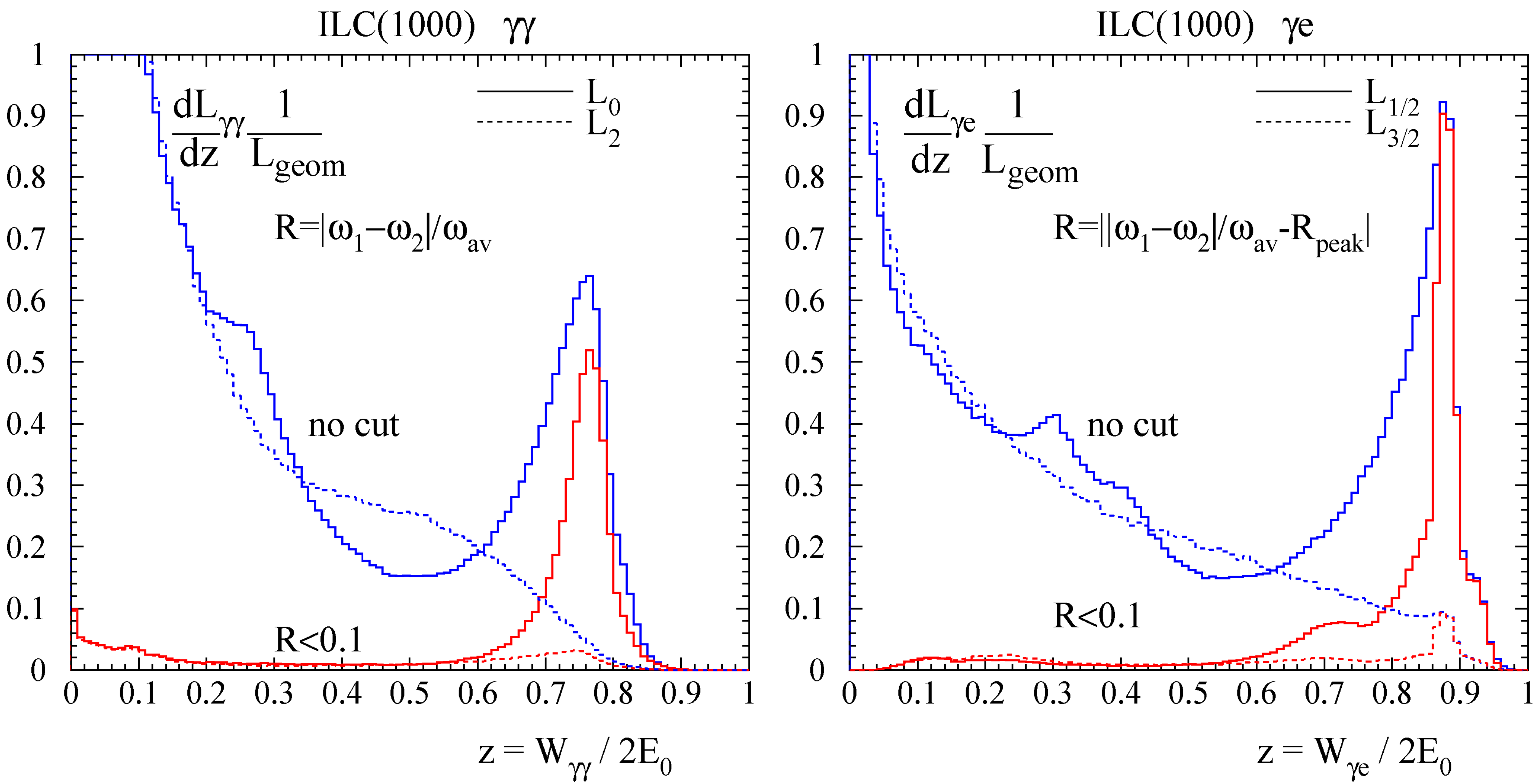
2E$_0$=500 GeV, λ=1 μm

2E$_0$=1000 GeV, λ=2 μm

The problem is solved, 20 mrad crossing angle is possible.

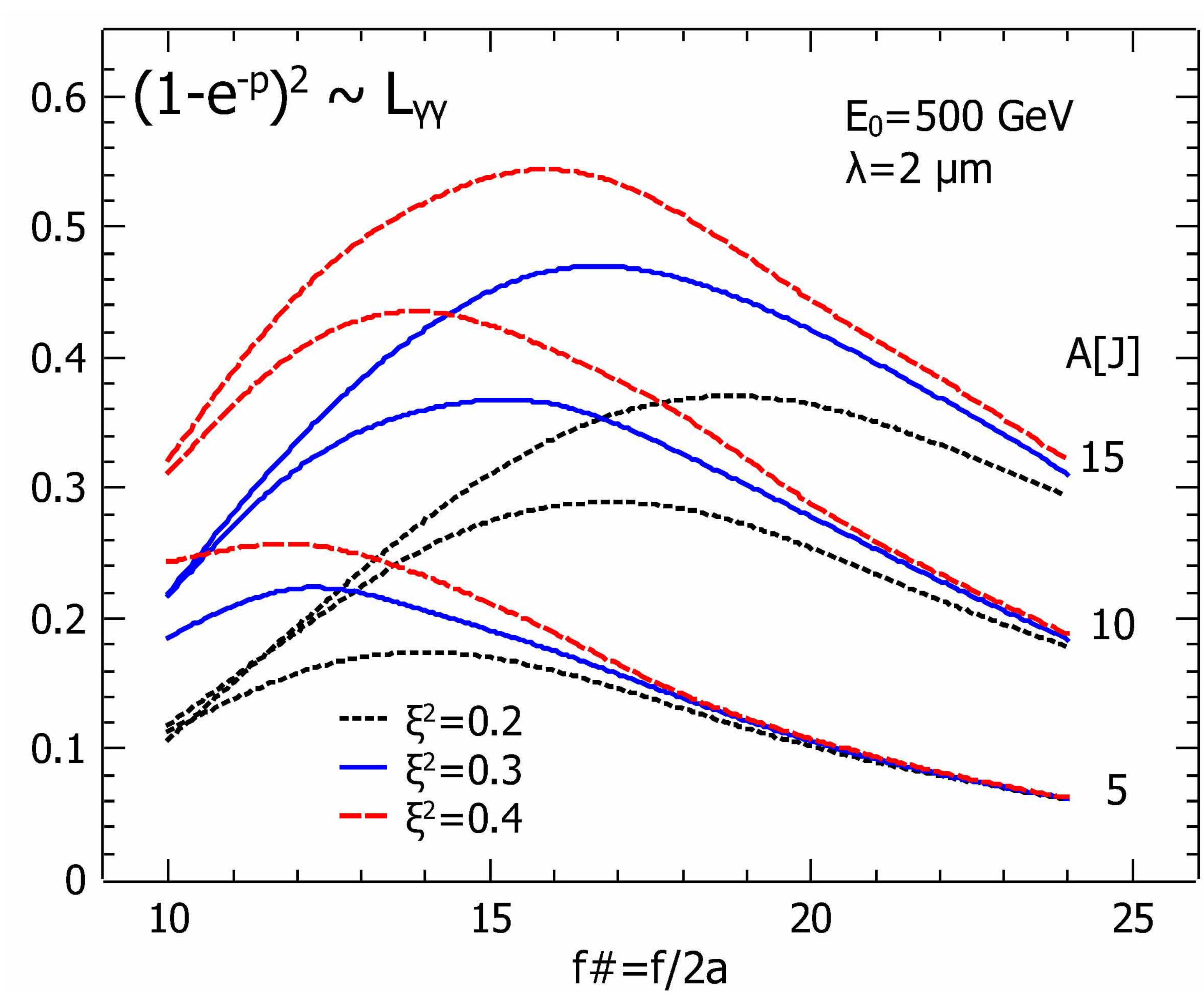
(If necessary, some additional reduction of θ_d can be obtained by some increasing of the σ_z without substantial loss of luminosity.)

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



Such spectra would be nice for study of X(750)

The laser flash energy for λ=2 μm for various nonlinear parameter ξ^2 and conversion probabilities.



Here the parameter

$$\xi^2 = \frac{e^2 \overline{F}^2 \hbar^2}{m^2 c^2 \omega_0^2} = \frac{2 n_\gamma r_e^2 \lambda}{\alpha}$$

characterizes nonlinear effects in Compton scattering and should be kept small (0.15-0.3), because

$$\omega_m = \frac{x}{x + 1 + \xi^2} E_0$$

The required flash energy is larger than at λ=1 μm by about 20%.

Some other special PLC requirements

(just reminding, all reported dozen times and published)

1. Crossing angle > 20 mrad.
2. Beam emittances and beta-functions at the IP as small as possible.
3. A special beamdump which can withstand absorption of very narrow photon beam.
4. Place for the laser system and the optics around the detector.
5. The detector design should allow replacement of elements in the forward region (<100 mrad).

Some of these requirements influence the ILC geometry and should be foreseen in the ILC design from the very beginning.

Physics motivation for PLC
(independent on a physics scenario)

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

1. the energy is smaller only by 10-20%
2. the number of interesting events is similar or even higher
3. access to higher particle masses (H,A in $\gamma\gamma$, charged and light neutral SUSY in γe)
4. higher precision for some phenomena ($\Gamma_{\gamma\gamma}$, CP-proper.)
5. different types of reactions (different dependence on theoretical parameters)

It is the unique case when the same collider allows to study new physics in several types of collisions at the cost of very small additional investments

Conclusion

- It is time to make a decision on the crossing angle in the ILC compatible with the PLC.
- If the ILC max. energy is $2E \geq 1$ TeV it has a big sense to plan a laser system with $\lambda \approx 2$ μm, then $\alpha_c = 20$ mrad is possible, which is OK for e+e- too.
- A space for the laser system and beamdump should be reserved.
- The PLC is a very physics/cost effective option of the ILC, does not add the capital cost (if special requirements are taken into account from the very beginning).