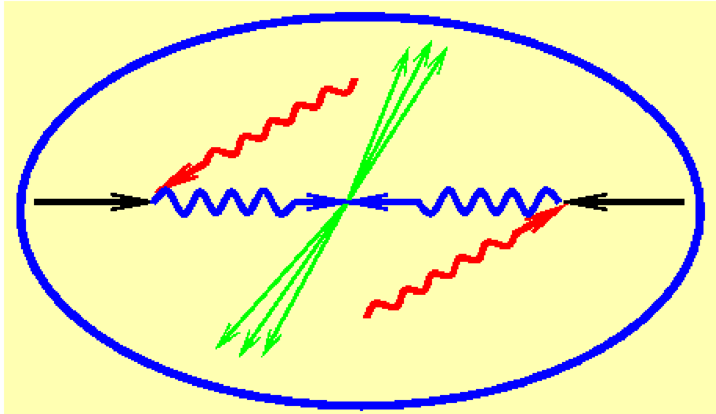

Photon collider at ILC: the crossing angle and laser wavelength

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

X(750)

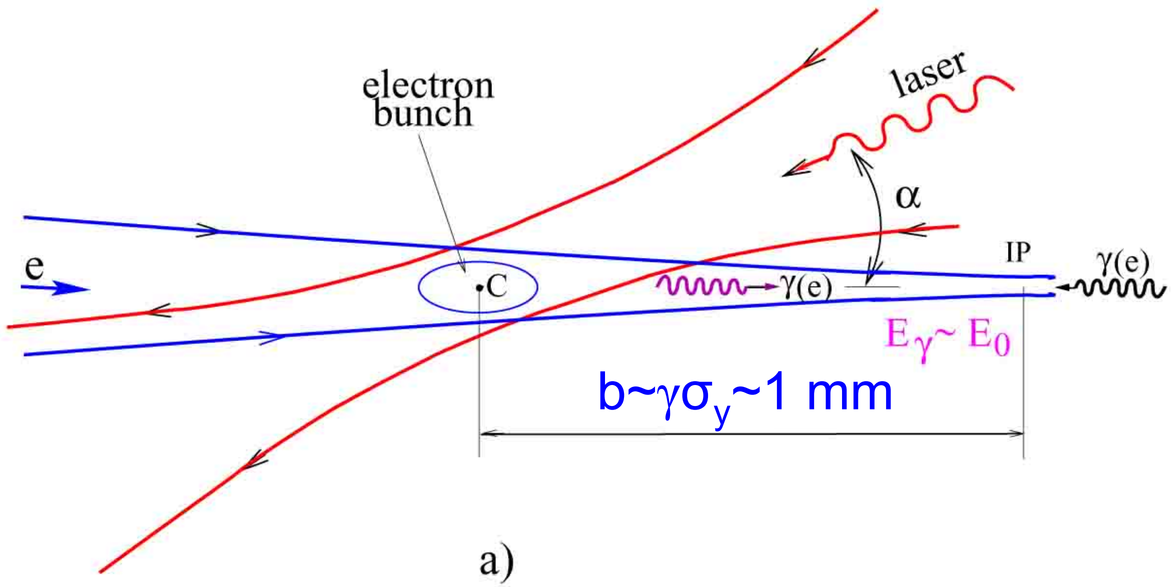
In 2015 two detector at LHC have observed the (fake) diphoton peak at $W_{\gamma\gamma}$≈750 GeV which caused a lot of excitement in HEP community (> 500 papers).

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."

I agree, now it requires minor modification, but if to do nothing, then soon such modification (crossing angle) will be practically impossible.

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

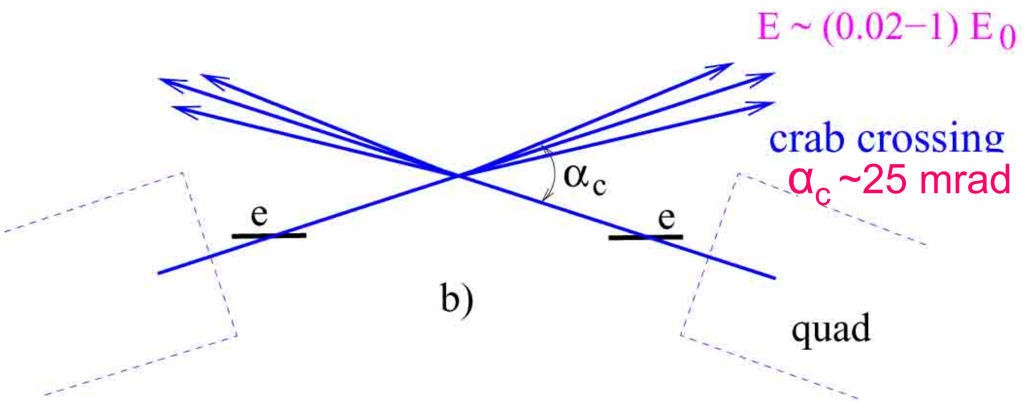


a)

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

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

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



b)

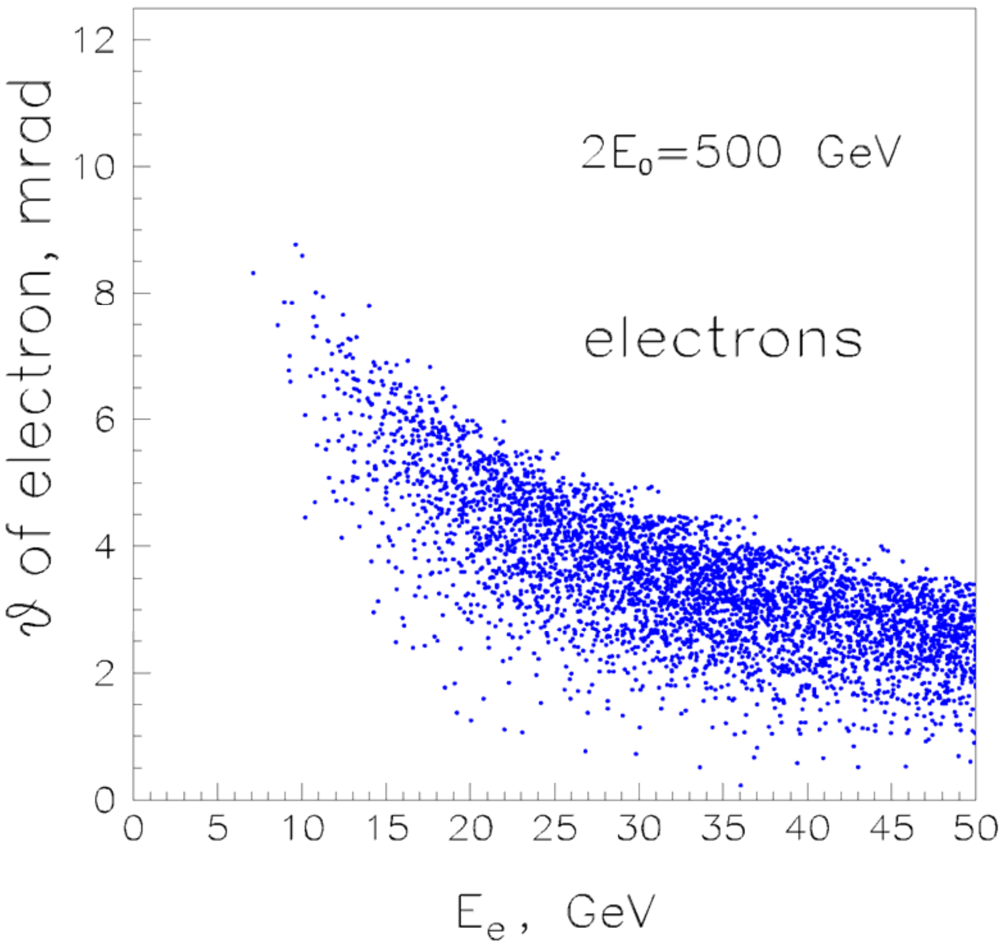
$x = 4.8$ is the threshold for
$\gamma\gamma_L \to e^+e^-$ at conv. reg.

ω_{max}~0.8 E_0

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

Properties of the beams after CP,IP

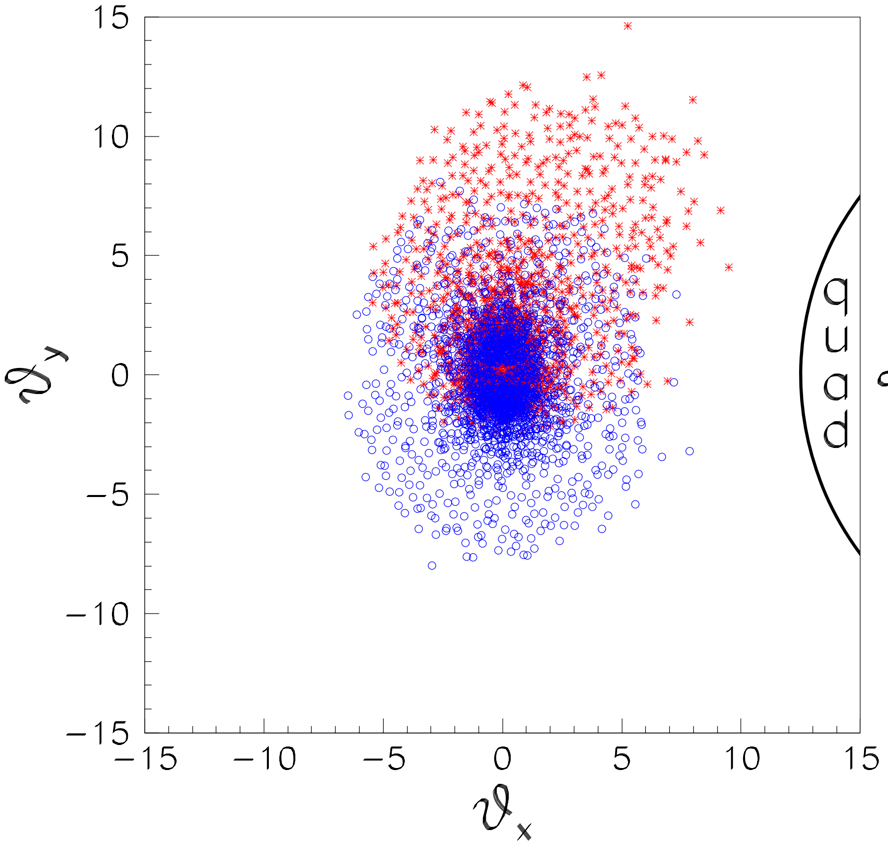
Angles of disrupted electrons after Compton scattering and interaction with opposing electron beam; $N=2\cdot10^{10}$, σ_z =0.3 mm



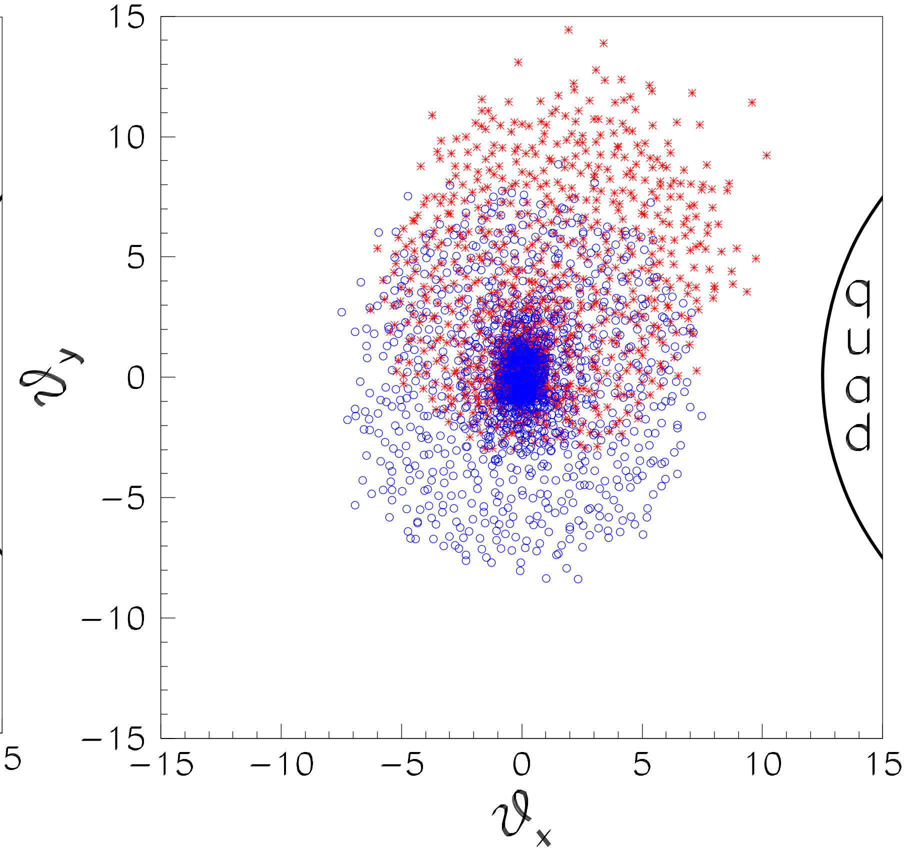
Low energy electron are deflected in the field of the opposing e-beam

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



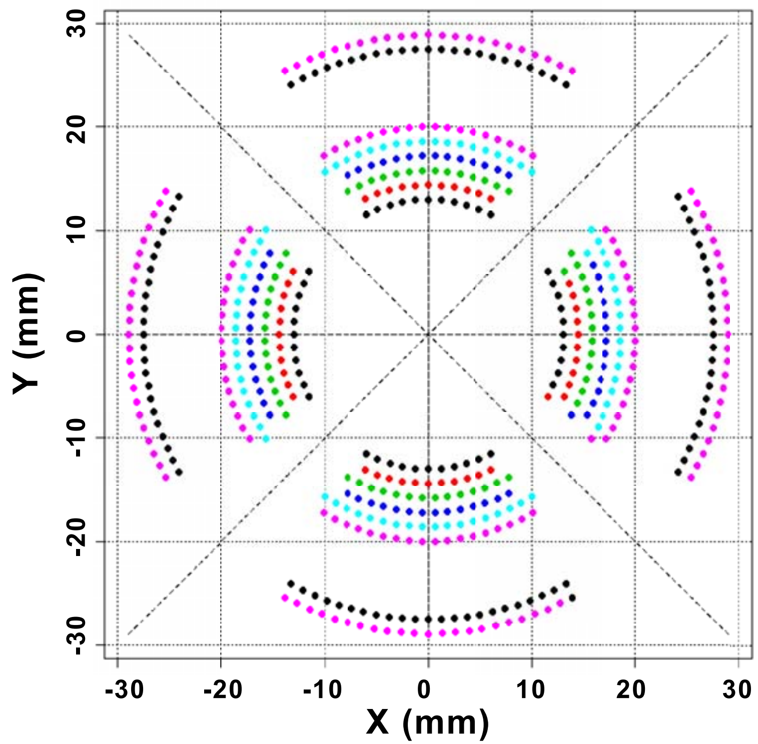
$2E_0$=500 GeV

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.



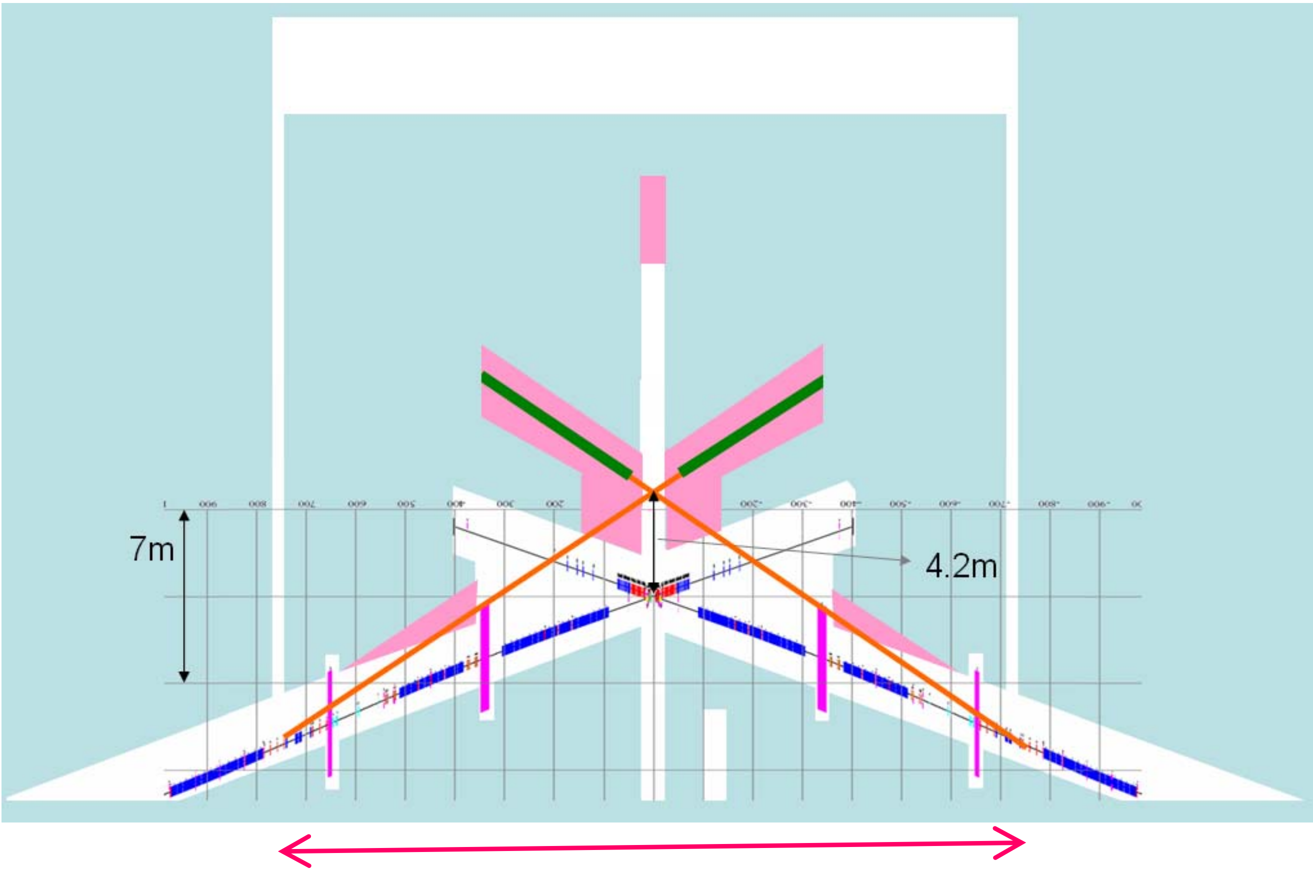
(At present warm hibrid quads are considered as well)

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

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 (or separate IP).

Influence of SR in the solenoid field on luminosity

(full simulation) Results on $L(\alpha_c)/L(0)$. (V.Telnov, physics/0507134)

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 $\Delta\varepsilon \sim (B\theta_c)^5$

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

The maximum disruption angle

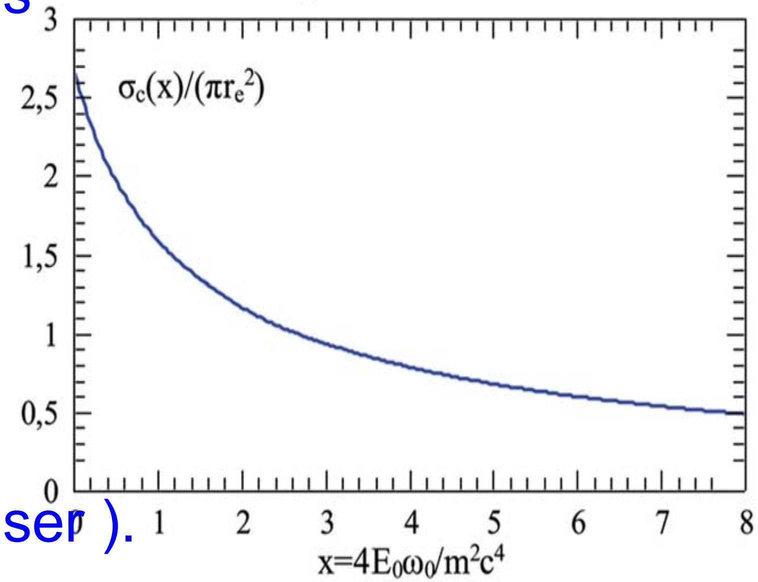
The collision probability at the CP is $p \sim t/\lambda_{sc}$, where $\lambda_{sc} \approx 1/n_\gamma \sigma_c$

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 $n \sim \frac{p\sigma_T}{\sigma_c(x)}$

The minimum energy after *n* Compton scatterings

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

Compton cross section



So, for the fixed collision probability (p) and laser wavelength the minimum energy is smaller for larger electron energy (because σ_c is smaller for larger x and one should use more powerful laser).

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

$$\theta_d \propto \sqrt{\frac{N}{\sigma_z E_{\min}}} \propto \sqrt{\frac{Np\omega_0}{\sigma_z}} \propto \sqrt{\frac{Np}{\sigma_z \lambda_{\text{las}}}}$$

Is 20 mrad possible?

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

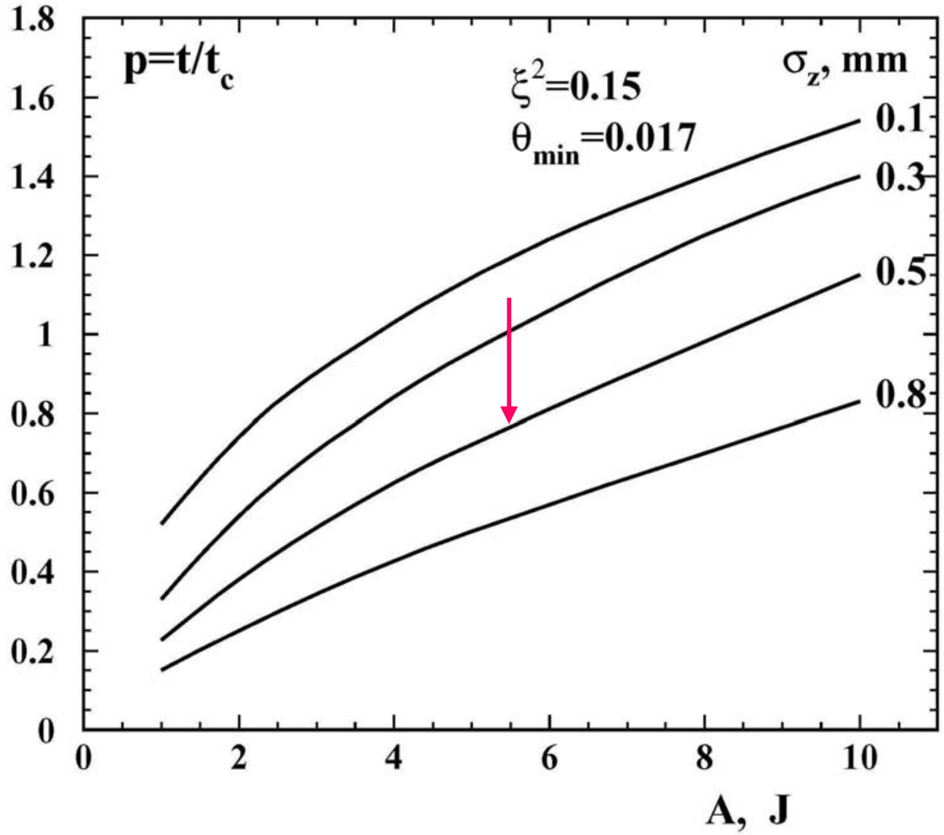
For the fixed λ the disruption angle $\vartheta \propto \sqrt{N/\sigma_z E_{min}} \propto \sqrt{Np/\sigma_z}$, where p – the number of collision length in the laser target, the conversion coefficient $k \approx 1 - e^{-p}$. The luminosity $L_{\gamma\gamma} \propto p^2 N^2 f / \sqrt{\sigma_z}$.

Solution 1. Reduce p by a factor of $(1.67)^2$=2.8, from the nominal p=1 to p=0.358 Then the luminosity drops by a factor of 4.4. That is not acceptable.

Solution 2. Make the bunch length 2.8 times longer. But to keep p=const one should increase the laser flash energy by 2.8 times. Nominally one needs A=5.5 J for E_0=100 GeV, and ξ^2=0.15 (5% shift of max. photon energy), now you need 15.5 J for 2E=200 GeV and 30 J for 2E=500 GeV (smaller σ_c), which are too high, not acceptable. Even with such increased flash energy the luminosity drops sqrt(2.8)=1.7 times.

Solution 3. To keep the flash energy A=const = 5.5 J (for the Higgs boson energy) and to increase the bunch length (reoptimizing the laser focusing), then p drops as well.

The dependence of p on σ_z



(laser focusing was optimized for each bunch length)

Taking σ_z=0.6 mm we get p=0.69 (was p=1 for σ_z =0.3 mm), which results in desired 1.7 times decrease of the disruption angle. In this case the luminosity decreases by a factor of 2.3. That is the best solution, but also unsatisfactory.

So, 20 mrad is too bad for $\gamma\gamma$, 23 mrad is more acceptable, for that one should increase σ_z to 0.4 mm, get p=0.9 and the luminosity decrease by a factor of 1.3.

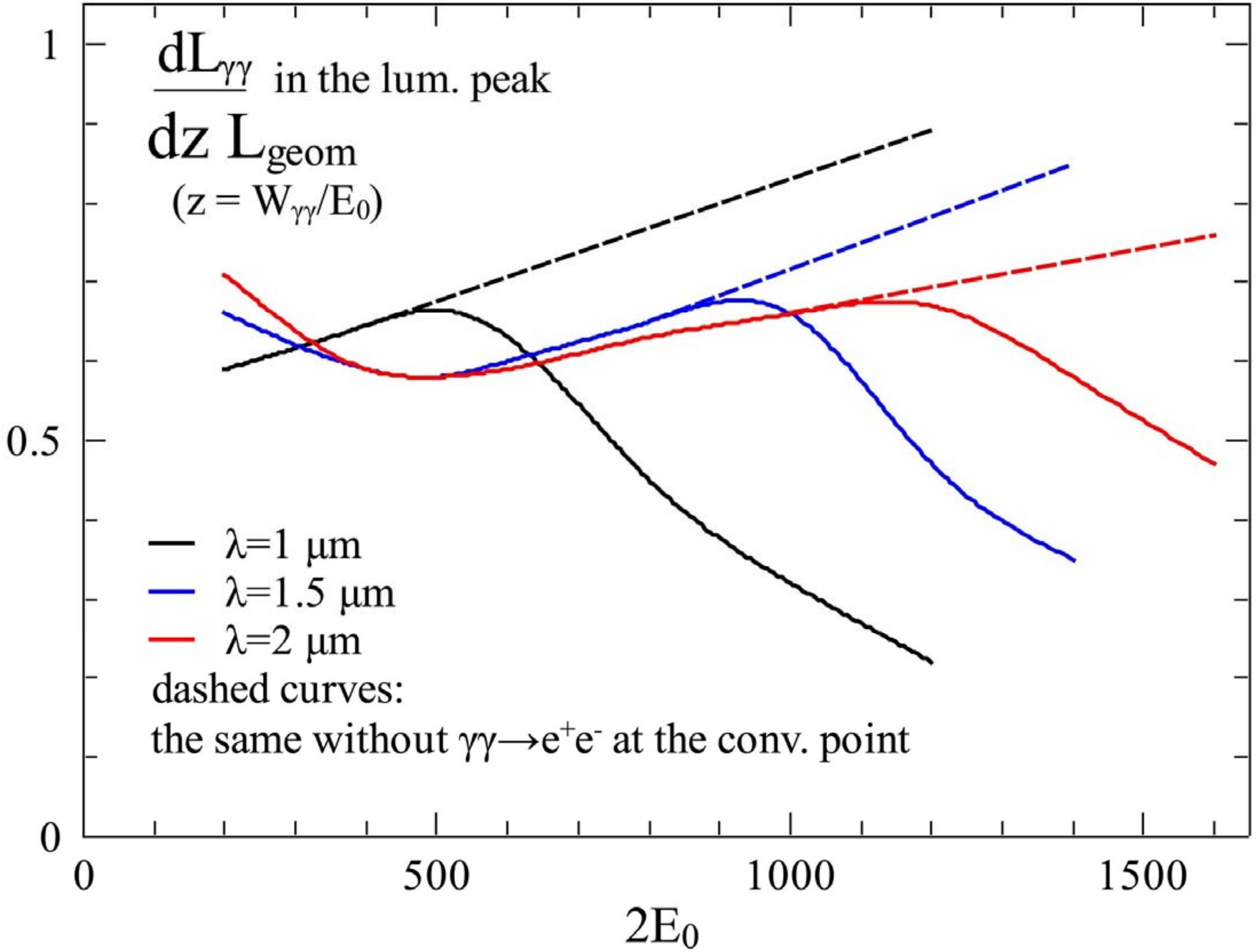
By now we varied only σ_z and p keeping λ=1 μm corresponding to wavelengths of most powerful lasers, which is optimum for $2E_0<500$-600 GeV.

Is the choice of the laser wavelength correct?

No, such a laser does not cover full energy range of the ILC ($2E_0=1$ TeV or somewhat larger)!

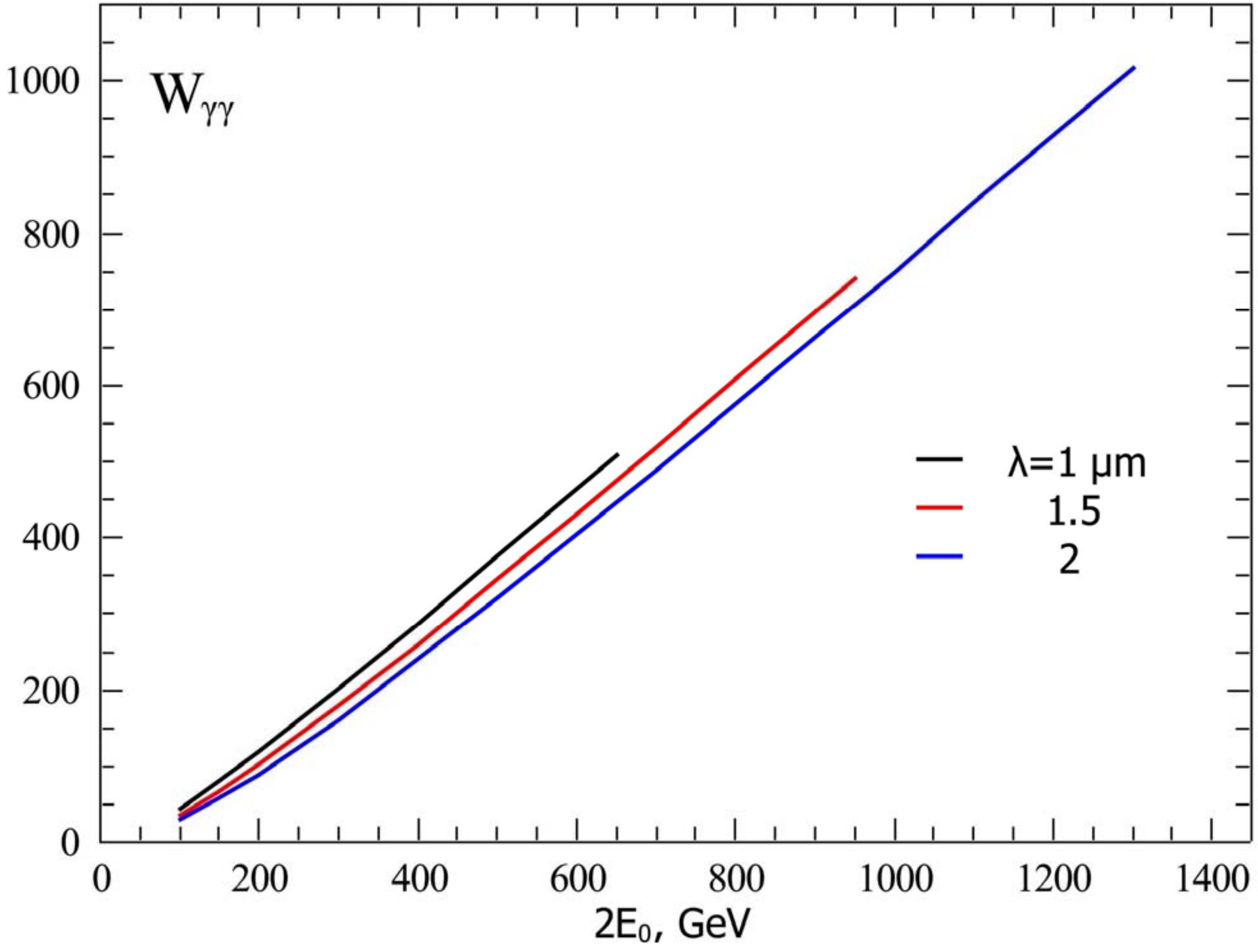
Let us consider the case of larger wavelength.

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 CP:



Indeed, λ=1 μm is not suitable for $2E_0$>500-600 GeV

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%

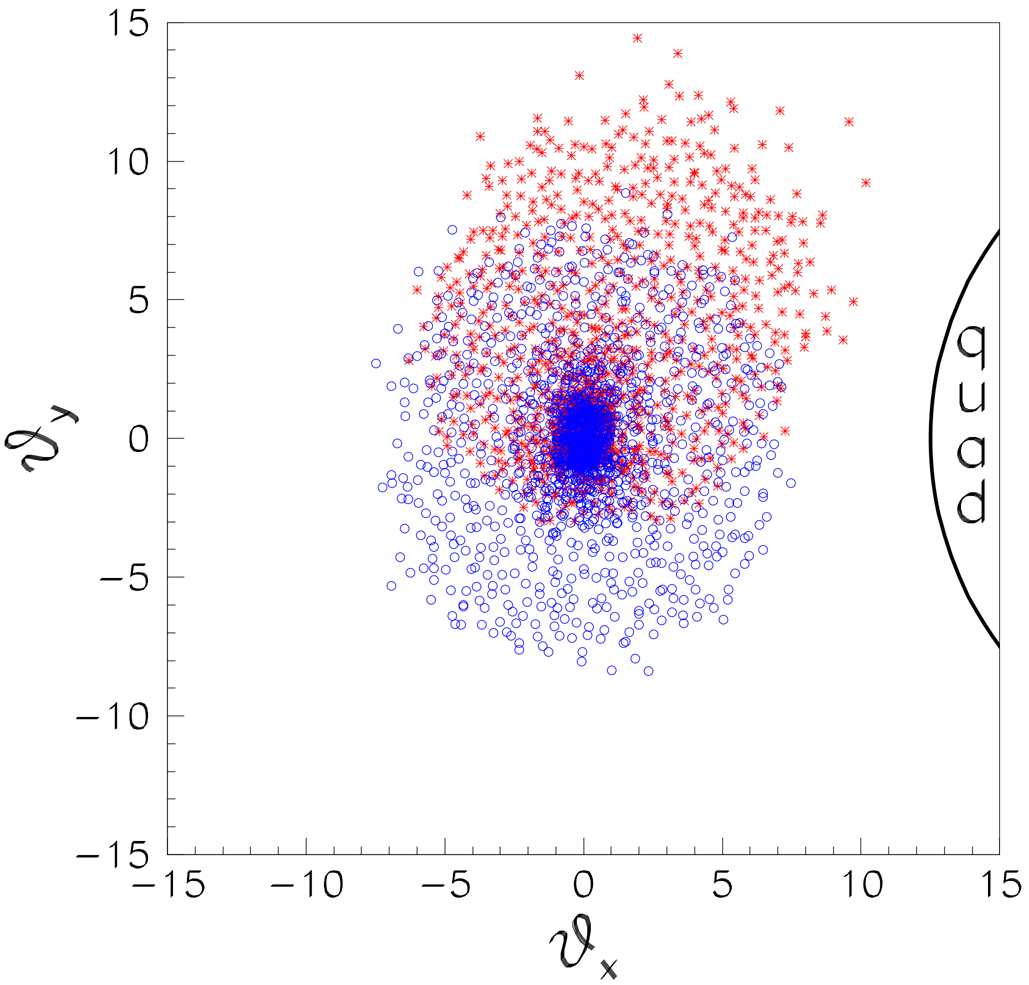
If the PLC will start to work after the ILC update to maximum energies, then it has sense to plan λ=2 μm from the very beginning.

There are two profits:

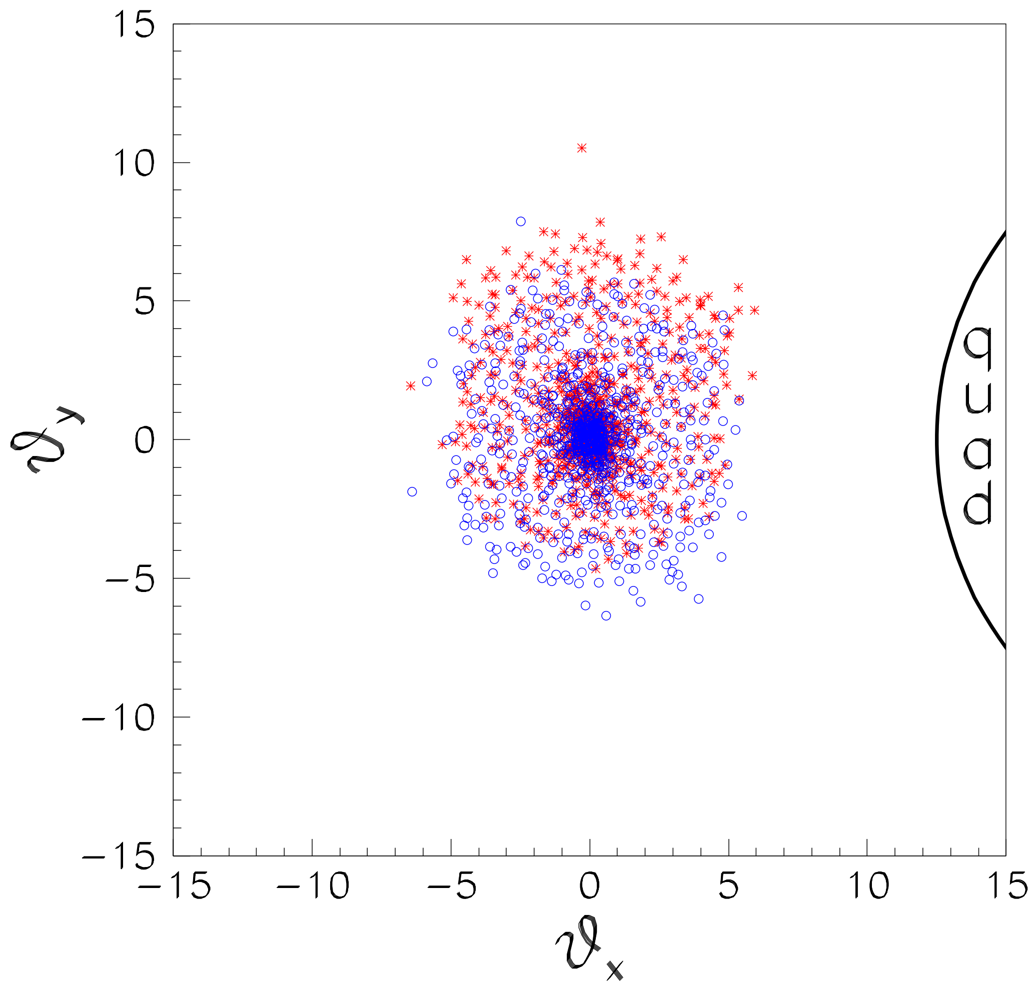
1) The same laser is suitable for the whole ILC energy range.

1) The minimum electron energy in the disrupted beams is 2 times larger than with λ= 1 μm and the disruption angle is sqrt(2)=1.42 times smaller. In this case θ_c= 20 mrad would be OK.

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

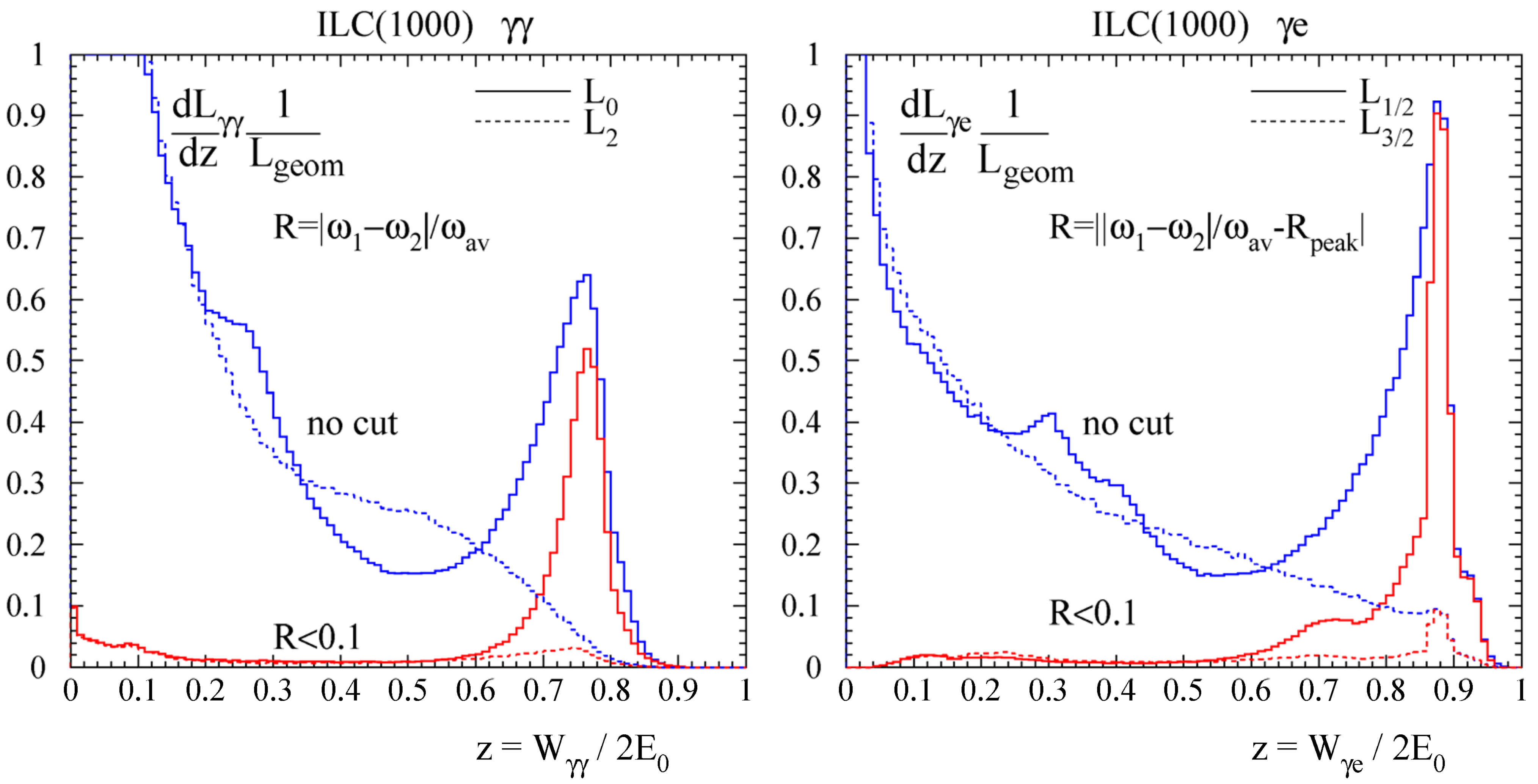


2E=500 GeV, λ=1 μm



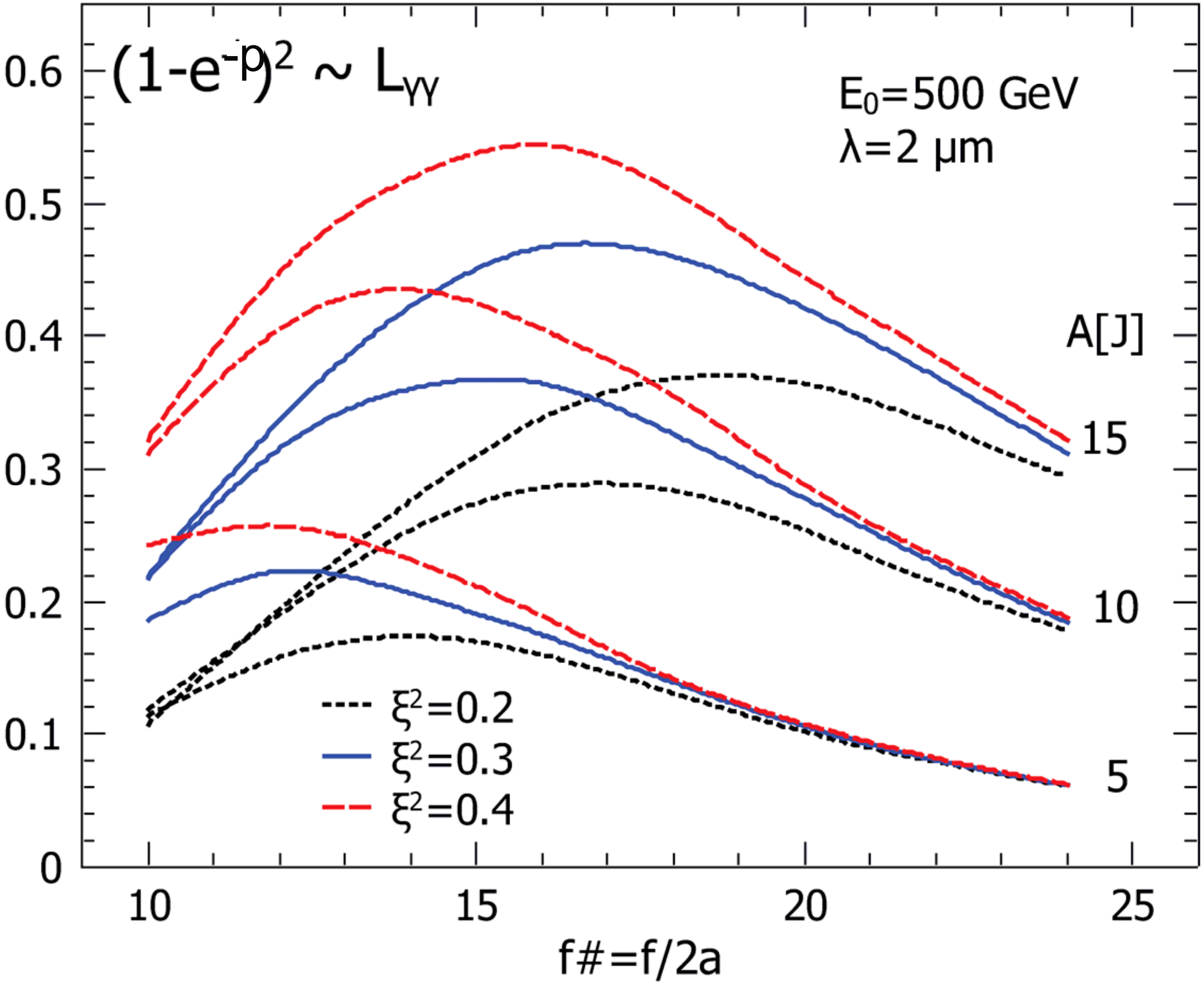
2E=1000 GeV, λ=2 μm

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 parameters (ξ^2=0.3 is OK) and conversion probabilities. It 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 > 20-23 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 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=1 TeV (or even somewhat larger) then it has a big sense to consider a laser system with $\lambda \approx 2\ \mu m$, then α_c=20 mrad is possible..
- 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).