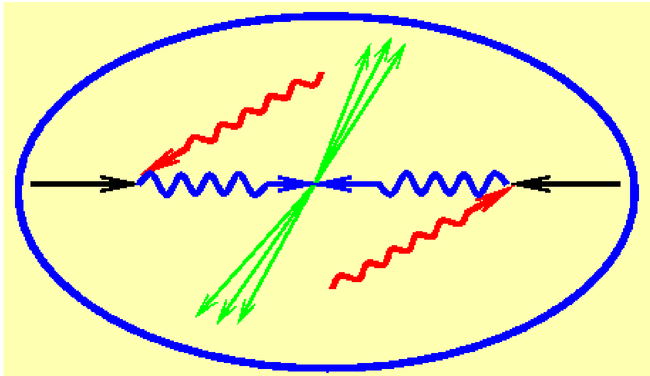

Consideration of a Photon collider without damping rings

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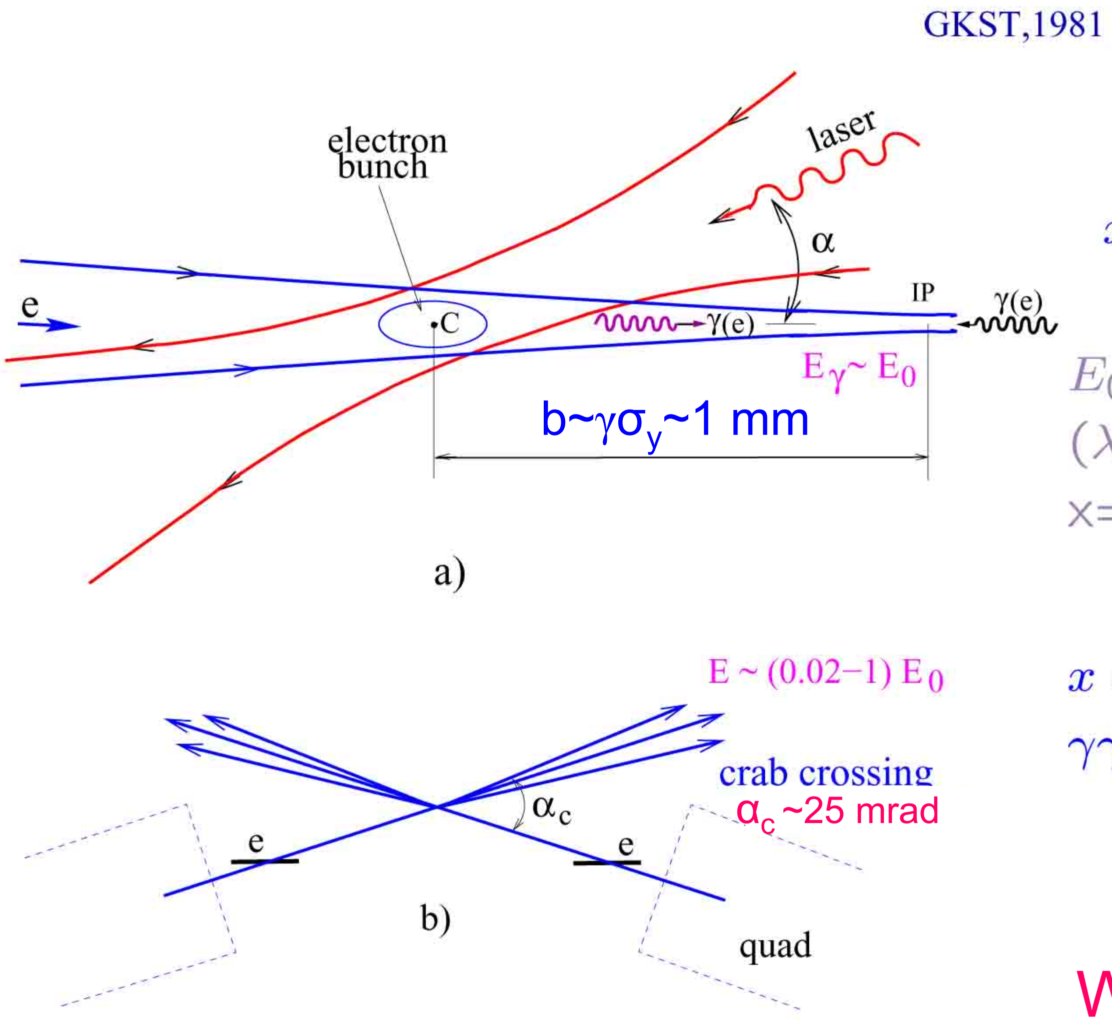
Scheme of $\gamma\gamma$, γe collider



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

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

$(\omega = 4\gamma^2\omega_0$ *at* $\omega \ll E)$

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

$(\lambda = 1.06\ \mu\mathrm{m}) \Rightarrow$

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.

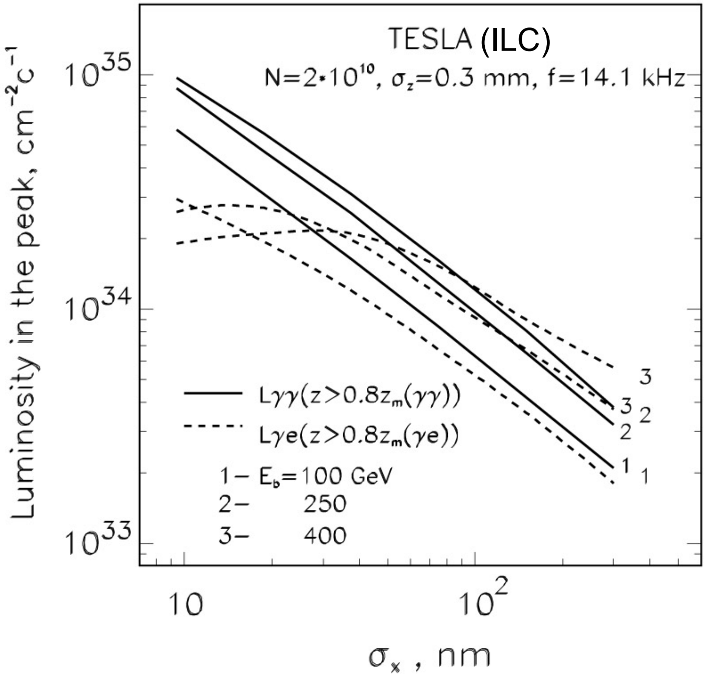
ω_{max}~0.8 E_0

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

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

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

Telnov,1998



Collision effects:

- Coherent pair creation ($\gamma\gamma$)
- Beamstrahlung (γe)
- Beam-beam repulsion (γe)

On the right figure:
the dependence of $\gamma\gamma$ and γe luminosities in the high energy peak vs the horizontal beam size (σ_y is fixed).

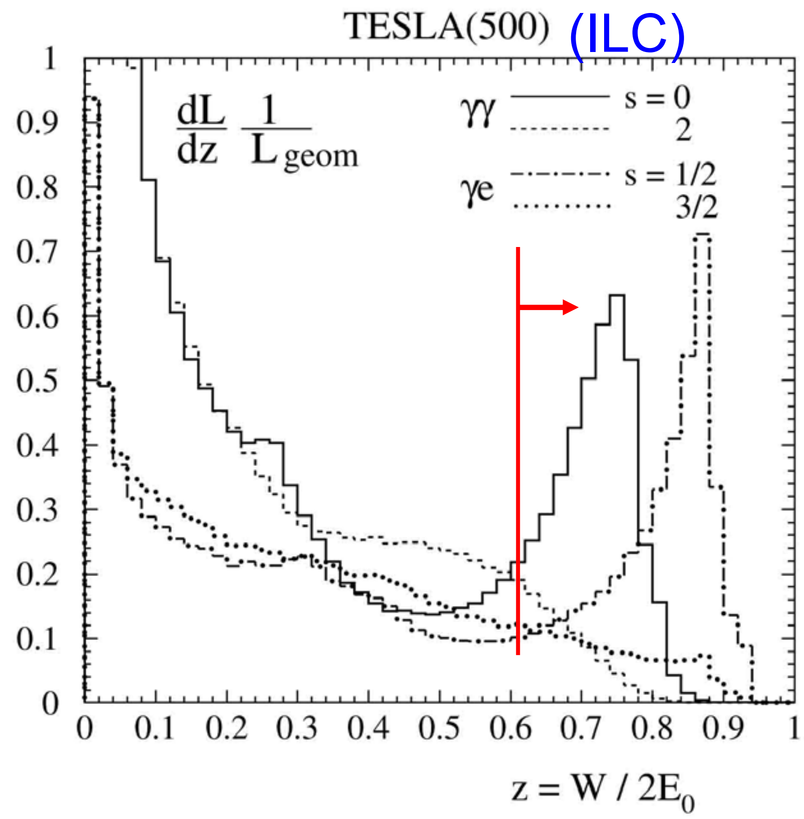
At the ILC nominal parameters of electron beams σ_x ~ 300 nm is available at $2E_0$=500 GeV. Having beams with smaller emittances one could obtain much higher $\gamma\gamma$ luminosity. Physics does not forbid an increase of the $\gamma\gamma$ luminosity by a factor of 30.

γe luminosity in the high energy peak is limited by beamstrahlung and beam repulsion.

So, one needs: ε_{nx}, ε_{ny} as small as possible and β_x , $\beta_y \sim \sigma_z$

Realistic luminosity spectra ($\gamma\gamma$ and γe)

(decomposed in two states of J_z)



Usually a luminosity at the photon collider is defined as the luminosity in the high energy peak, $z>0.8z_m$.

For the nominal RDR ILC beams (from DRs)

$L_{\gamma\gamma}(z>0.8z_m) \sim 0.17 L_{e+e-}(\text{nom})$

(but cross sections in $\gamma\gamma$ are larger by one order!)

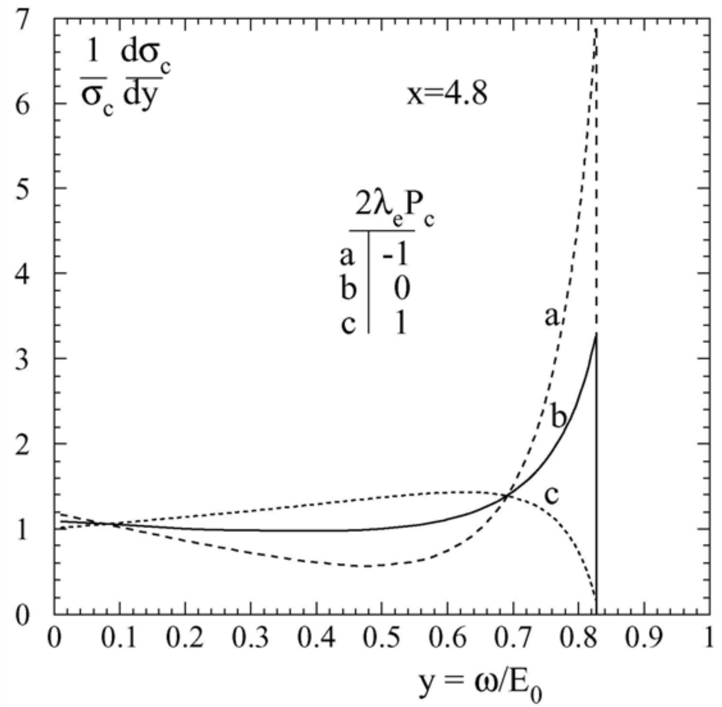
Due to chromo-geometric aberrations the minimum β_x~4mm (A.Seryi), (while $\beta_y \sim \sigma_z \sim$0.3-0.4 mm)

In the general case, at the ILC $L_{\gamma\gamma}(z>0.8z_m) \sim 0.1 L_{e\text{-}e\text{-}}\text{geom})$

(not valid for multi-TeV colliders with short beams(CLIC) due to coherent e+e- creation)

Importance of the electron polarization

Spectrum of the Compton scattered photons

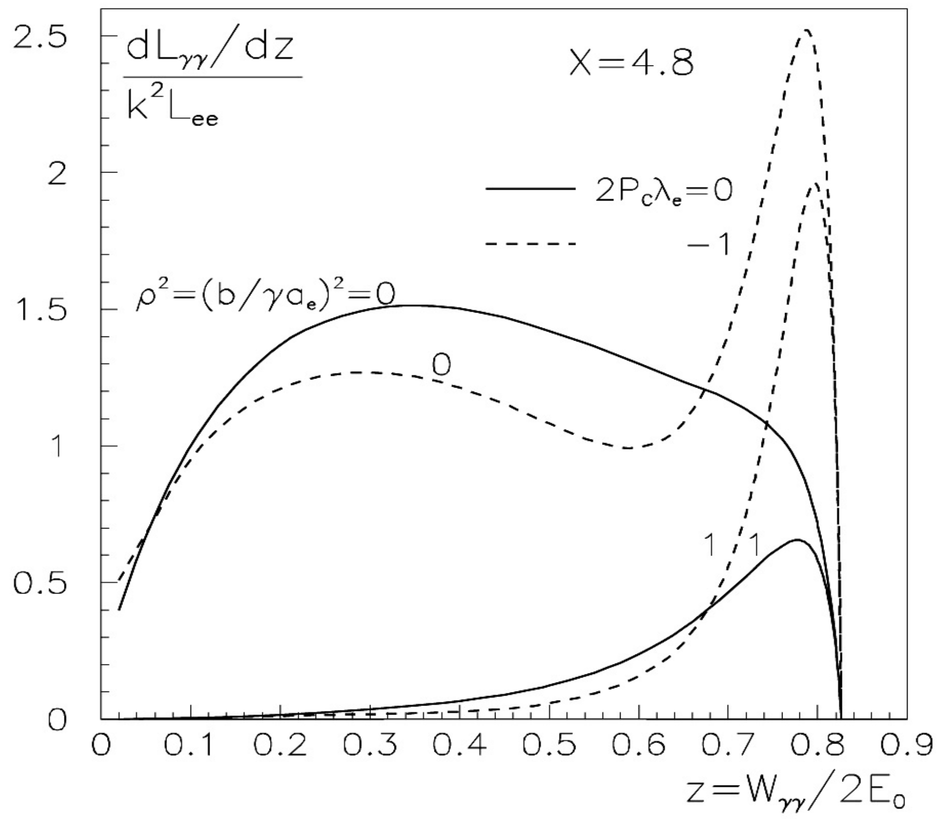


λ_e – electron longitudinal polarization
P_c – helicity of laser photons, $x \approx \frac{4E_0\omega_0}{m^2c^4}$

The electron polarization increases the number of high energy photons nearly by factor of 2).

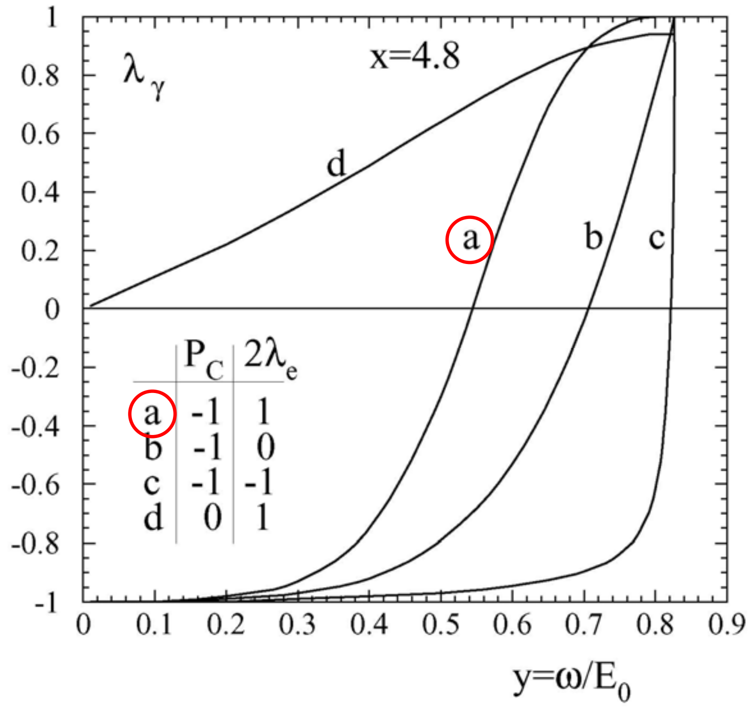
Ideal luminosity distributions, monohromatization

(a_e is the radius of the electron beam at the IP, b is the CP-IP distance)



Electron polarization increases the $\gamma\gamma$ luminosity in the high energy peak up to a factor of ~3-4 (at large x).

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



Highest energy scattered photons are polarized even at λ_e=0 (see (b))

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

The cross section of the Higgs production

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

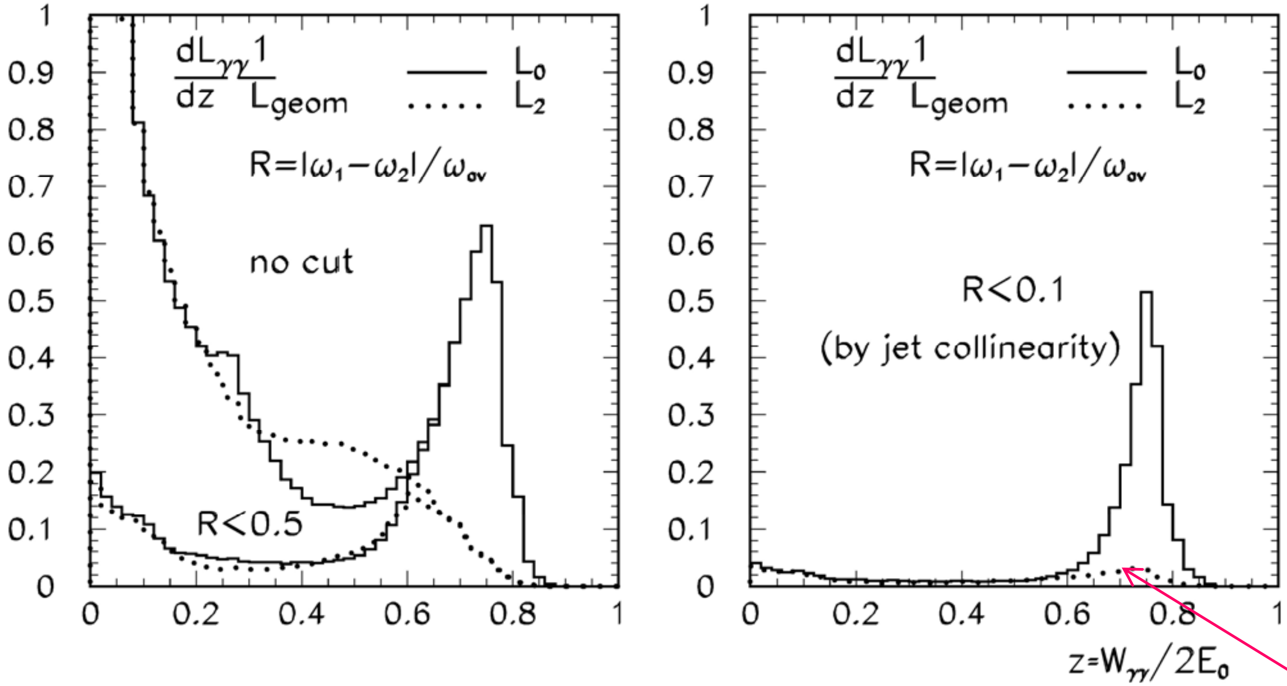
The cross section for main backgound

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

The electron polarization makes the region with a high polarization (at $\omega \sim \omega_{m)}$ wider (compare a and b).

Realistic luminosity spectra at the PLC ($2\lambda_e$=0.85)

ILC-TESLA(500)



$\gamma\gamma$

$\gamma\gamma$ luminosity with J=2 is smaller than that with J=0 by factor of 10-20 (that is very important for extraction of the Higgs(130)

Comparizon of transverse emittances in damping rings and photo-guns

The ILC DR (polarized): $\varepsilon_{nx}=10^{-3}$ cm, $\varepsilon_{ny}=3.6\cdot10^{-6}$ cm, β_x~4 mm

RF guns (3 nC, unpolarized): $\varepsilon_{nx}=3\cdot10^{-4}$ cm, $\varepsilon_{ny}=3\cdot10^{-4}$ cm, β_x~2 mm

DC guns (polarized): $\varepsilon_{nx}=7\cdot10^{-3}$ cm, $\varepsilon_{ny}=7\cdot10^{-3}$ cm, β_x~4 mm

$L_{geom} \sim F_{(pol.ench.)}/(\varepsilon_{nx}\varepsilon_{ny}\beta_x\beta_y)^{1/2}$ $\quad F_{pol.ench} \sim 2\text{-}3.5$ (depends on the energy)

Very approximately with account of β_x variation (chromo-geom.aberrations):

L(DR)/ L(RFguns,unpol)~ 7-12
L(DR)/ L(DCguns,pol) ~ 100

Therefore until now DRs were considered as a preferable source of electrons for the PLC.

Methods of additional cooling electrons after guns or DR was suggested (laser cooling), but it is very difficult.

What to do?

First of all, it is necessary to develop polarized RF guns with low emittances.

If their emittances will be determined by space charge effects (as in unpolarized RF-guns)

L(DR)/ L(RFguns,unpol)~ 3

This is better, but still the luminosity is higher with DRs,

new ideas are needed.

Longitudinal emittances

Let us compare longitudinal emittances needed for ILC with those in RF guns.

At the ILC $\sigma_E/E \sim 0.3\%$ at the IP (needed for focusing to the IP), the bunch length $\sigma_z \sim 0.03$ cm, $E_{min} \sim 75$ GeV that gives the required normalized emittance

$$\varepsilon_{nz} \approx (\sigma_E/mc^2)\sigma_z \sim 15 \text{ cm}$$

In RF guns $\sigma_z \sim 0.1$ cm (example) and $\sigma_E \sim 10$ keV, that gives

$$\varepsilon_{nz} \sim 2 \cdot 10^{-3} \text{ cm},$$

or 7500 times smaller than required for ILC!

So, photoguns have much smaller longitudinal emittances than it is needed for linear collider (both e+e- or $\gamma\gamma$).

How can we use this fact?

A proposed method

Let us combine many low charge, low emittance beams from photo-guns to one bunch using some differences in their energies. The longitudinal emittance increases approximately proportionally to the number of combined bunches while the transverse emittance (which is most important) remains almost constant.

It is assumed that at the ILC initial micro bunches with small emittances are produced as trains by one photo gun.

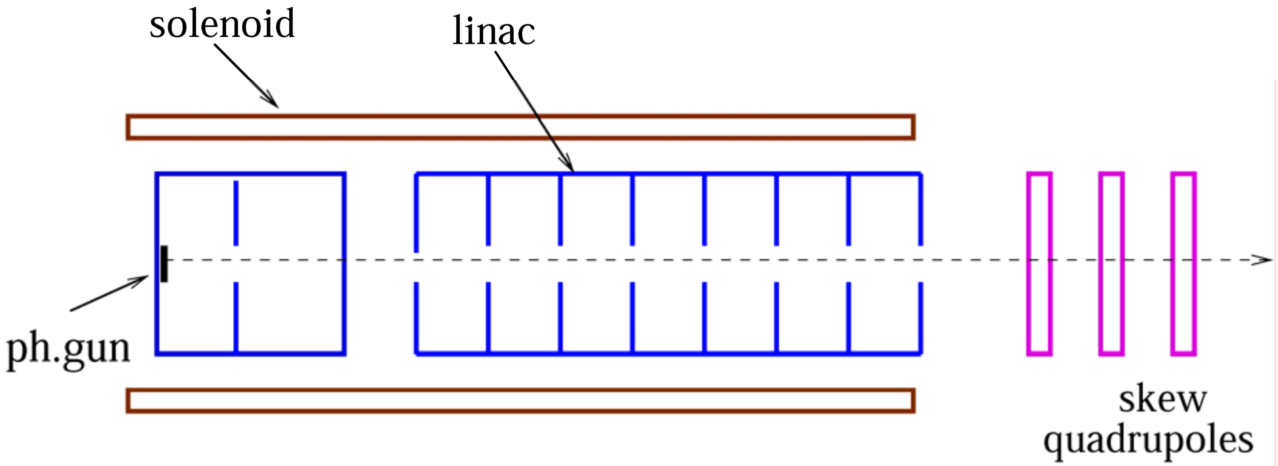
In the CLIC case the distance between bunches is very small therefore micro bunches are produced by many separate photo-guns.

Each gun is followed by round-to-flat transformer (RFT). RFT does not change the product of transverse emittances, but it is easier to conserve emittances manipulating with flat beams in the horizontal plane.

Below the scheme for the ILC case is considered.

Round to flat transformer (RFT)

In 1998 Ya. Derbenev has found that using the RF gun inside the solenoid and following skew quadrupoles one can transform a round beam (from an electron gun) to a flat beam with an arbitrary aspect ratio.



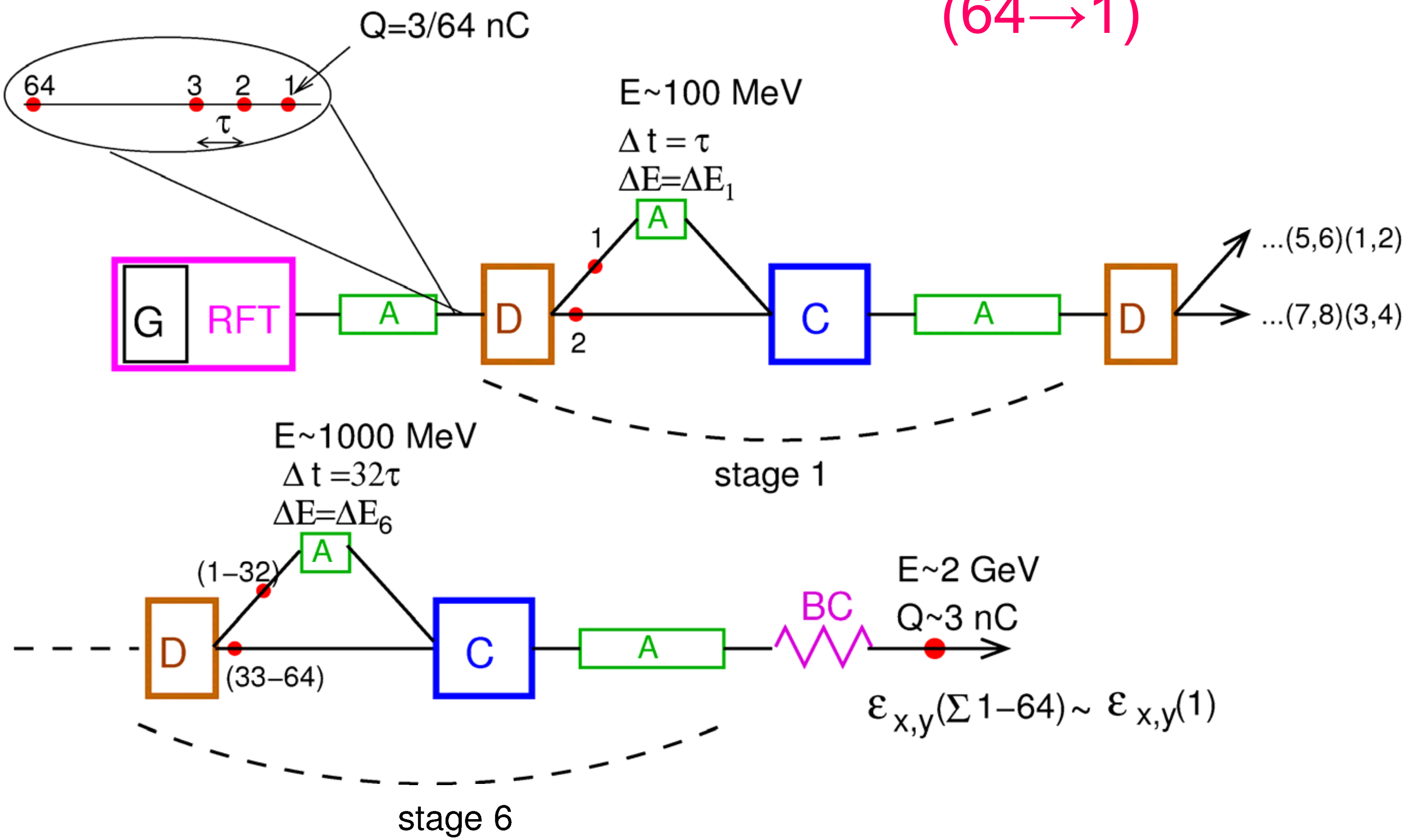
After such transformation $\varepsilon_{nx}\varepsilon_{ny}=\varepsilon^0_{nx}\varepsilon^0_{ny}=(\varepsilon^G_n)^2=\text{const}$

$$\varepsilon_{ny}=\frac{1}{2}\beta\sigma_{r'}^2 \quad R=\frac{\varepsilon_{nx}}{\varepsilon_{ny}}\approx\frac{2\sigma_r^2}{\beta^2\sigma_{r'}^2} \text{ (at } \varepsilon_{nx.}\gg\varepsilon_{ny}) \quad \beta=\frac{2p_z}{eB}$$

The ratio R=100 was demonstrated at FNAL and this is not the limit.
The initial goal of the R-F-transformer was the e+e- linear collider, but now there are much wider applications.

Scheme of combining one bunch from the bunch train (for ILC)

(64→1)

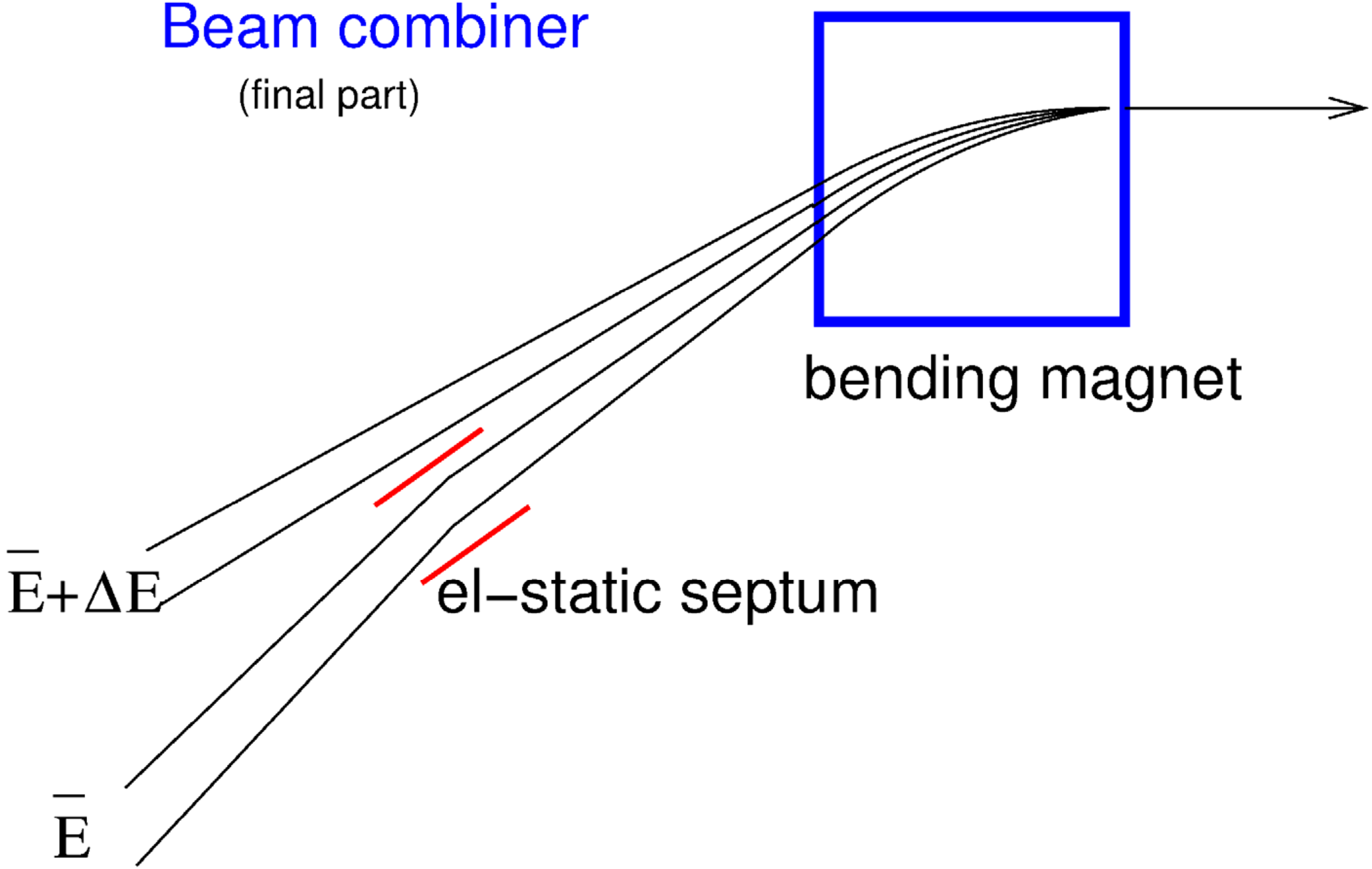


G –photogun, A –RF–cavities (accel), RFT –round to flat transformer,

D –deflector, C –beam combiner, BC –bunch compressor

Beam combiner

(final part)



Description of the scheme

After the gun and RFT the train passes several stages of deflectors-combiners. Each two adjacent bunches are redirected by the deflector (D) (transverse RF-cavity) into two beamlines which have difference in length equal to distance between bunches. One of these beamlines contains a weak RF-cavity which adds ΔE to the beam energy. Further these two beams are combined in a dispersion region of the combiner (C) using the difference in beam energies.

In order to combine the whole train to one bunch the procedure is repeated $m=\log_2 n_b$ times. The scheme shown above assumes $n_b=64$, that needs 6 stages. The energy between stages is increased by linacs in order to avoid emittance dilution due to the space charge effects. At the end, the final bunch is compressed down to required bunch length by a standard bunch compressor.

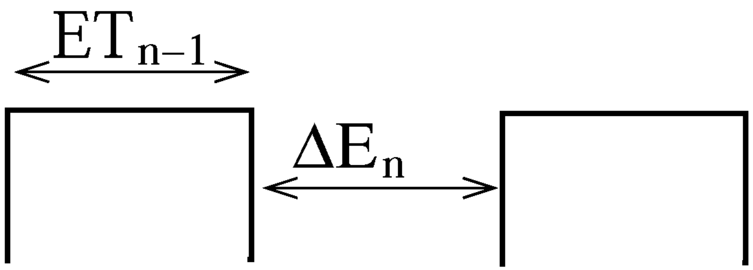
Choice of ΔE_i

In principle, one can combine the final bunch in a such way that sub-bunches are spaced in energy equidistantly and the total energy spread is $\Delta E_{tot}=n_{b-1}\ \Delta E_1$, where ΔE_1 is the energy several times larger than σ_E in the sub-bunch.

However, it is difficult to combine two beams with very small energy gap. Sub-beams have natural transverse sizes associated with their emittances, the distance between two sub-beams in the combining region should be larger than these beam sizes. Smaller energy gap means larger dispersion in the combining region. Larger dispersion means larger bending angles and larger distances that may be problematic for final stages with high energies. Therefore ΔE_n should increase with the stage number in order to make easier technical problems. It is important only that ΔE_1 is several times larger than the initial sub-beam energy spread and the final longitudinal emittance satisfies the ILC requirement.

Choice of ΔE_i (continue)

For example, let us require the gap between two combining beams at the stage n $\Delta E_n = ET_{n-1}$, where ET_n is the total energy spread at the stage n, then $ET_n = 3^{n-1}\Delta E_1$.



If ΔE_1=40 keV at E~50-100 MeV

then ET_6=9.7 MeV at E~1 GeV.

After the bunch compression at E~2-3 GeV by a factor of 3 the energy spread will be about σ_E~10 MeV ($\sigma_E/E=10^{-4}$ at E=100 GeV), that is better than necessary.

Bunch length during beam combining

In order to decrease space charge effects (for transverse emittance) bunches should be as long as possible, however for long bunches RF- acceleration induces the longitudinal emittance

$$\varepsilon_{rf} \approx \sqrt{3}(\gamma_f - 1)k^2\sigma_z^3, \quad k = 2\pi / \lambda$$

A reasonable choice σ_z~1-1.5 mm for λ~20 cm. If necessary, RF induced longitudinal emittance can be canceled by deceleration in cavities with 2 (or 4) times shorter wavelength.

After beam combining the final bunch is compressed by a facor of 3 down to the required bunch length (σ_z=0.4 mm for ILC).

Emittances in RF-guns

There are two main contribution to transverse emittances in RF guns:

1. Space charge induced normalize emittance;
2. Thermal emittance.

The space charge emittance $\varepsilon_{sc} \sim 10^{-4}$ Q[nC] cm

The thermal emittance $\varepsilon_{th} \sim 0.5 \cdot 10^{-4}$ R[mm], cm

Assuming $R^2 \propto Q$ and R=1 mm at 1 nC, we get for Q=3/64 nC

$$\varepsilon_{sc} \sim 0.5 \cdot 10^{-5} \text{ cm}, \ \varepsilon_{th} \sim 10^{-5}$$

$$\rightarrow \varepsilon_{n,\,tot} \sim 10^{-5} \text{ cm}$$

After RFT with the ratio 100

$$\varepsilon_{nx} \sim 10^{-4} \text{ cm}, \ \varepsilon_{ny} \sim 10^{-6} \text{ cm}.$$

Luminosities

Beam parameters: $N=2\cdot10^{10}$ (Q~3 nC), $\sigma_z=0.4$ mm

Damping rings(RDR): $\varepsilon_{nx}=10^{-3}$ cm, $\varepsilon_{ny}=3.6\cdot10^{-6}$ cm, $\beta_x=0.4$ cm, $\beta_y=0.04$ cm,

RF-gun (Q=3/64 nC) $\varepsilon_{nx}\sim10^{-4}$ cm, $\varepsilon_{ny}=10^{-6}$ cm, $\beta_x=0.1$ cm, $\beta_y=0.04$ cm,

The ratio of geometric luminosities

$$L_{RFgun}/L_{DR}=12\sim10$$

So, with polarized RF-guns one can get the luminosity ~10 times higher than with DR.

In the case of unpolarized RF-guns the effective luminosity will be higher than with DR by a factor of 3-4.

Comparison of polarized and unpolarized beams

$\rho=(b/\gamma)/\sigma_y$

The following cases are considered:

2E=200 GeV, x=1.8

polarized 85%, $\rho=3$
unpolarized, $\rho=3$

2E=500 GeV, x=4.5

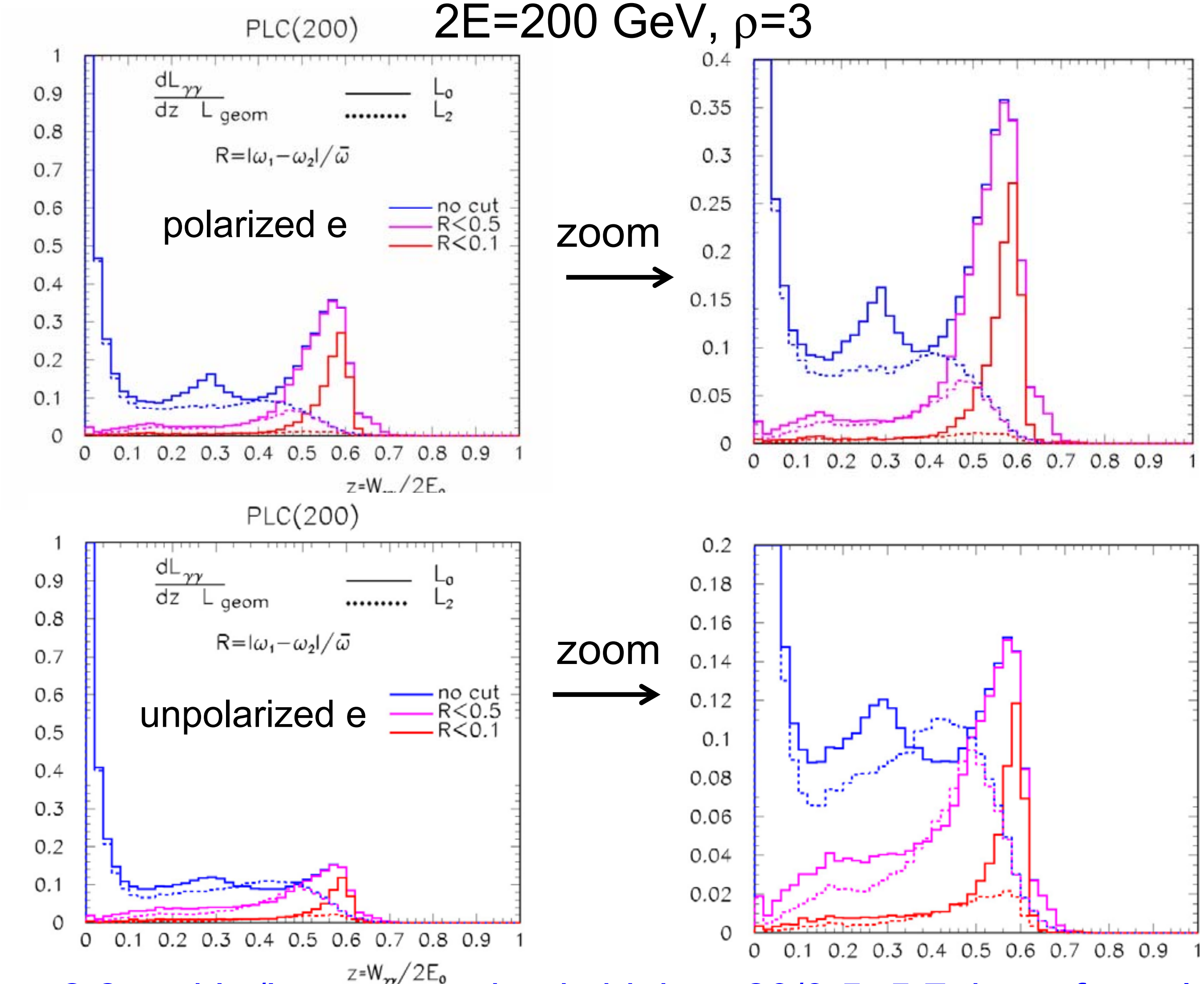
polarized 85%, $\rho=3$
unpolarized, $\rho=3$

Laser photons have 100% helicity in all examples.

- To see better the luminosity with central collisions a cut on the parameter $R=|\omega_1-\omega_2|/\langle\omega\rangle$ is applied.
- The increased CP-IP distance b is used in order to suppress low $W_{\gamma\gamma}$ luminosity (the case $\rho=3$).

Comparison of polarized and unpolarized electron beams,

2E=200 GeV, ρ=3



at $z>0.85z_m$

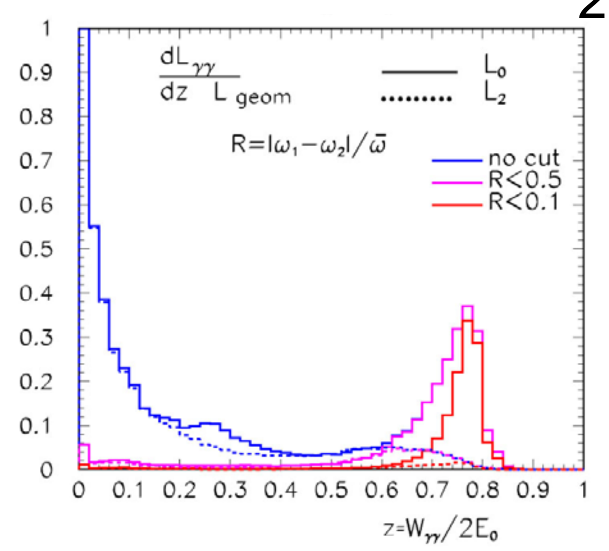
$L^p{}_0/L^p{}_2$~20

$L^{up}{}_0/L^{up}{}_2$~3.55

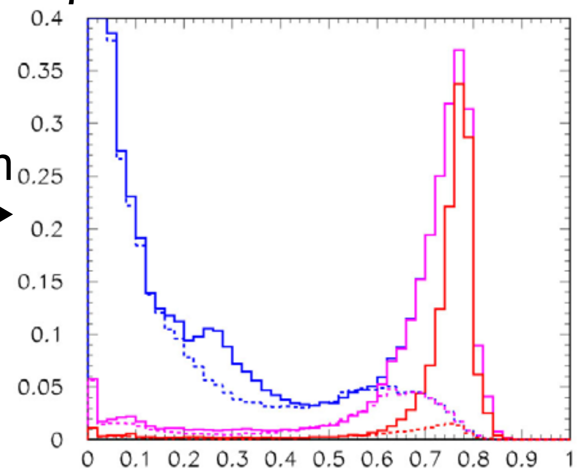
$L^p{}_0/L^{up}{}_0$=2.2 and L_0/L_2 suppression is higher 20/3.5=5.7 times for pol. beams.
Nevertheless, γγ collisions with unpol. electrons have rather good polarization properties, sufficient for study of many processes.

Comparison of polarized and unpolarized electron beams

2E=500, ρ=3

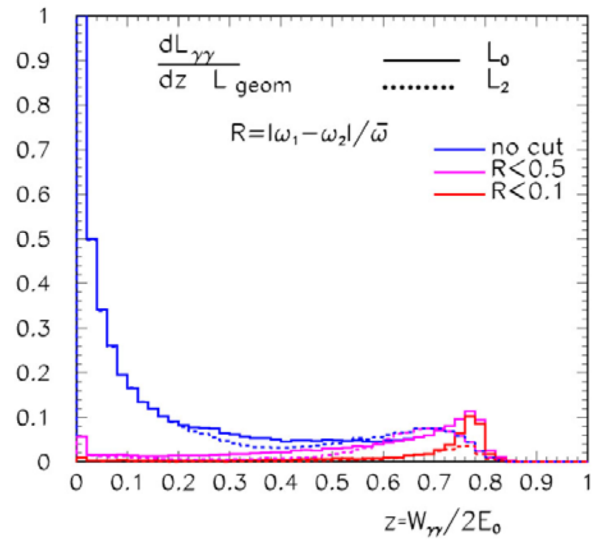


zoom →

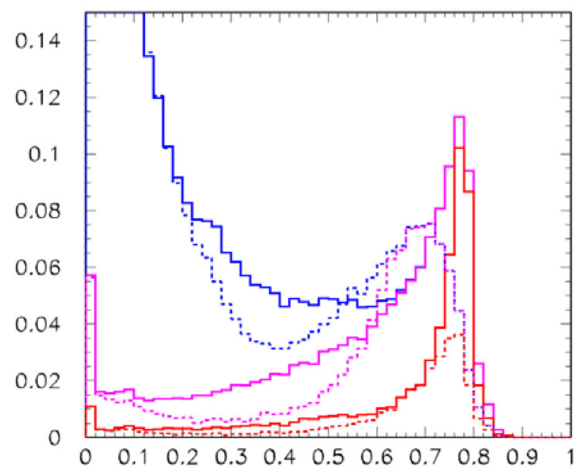


at $z>0.85z_m$

$L^p_0/L^p_2 \sim 20$



zoom →



$L^{up}_0/L^{up}_2 \sim 2.5$

$L^p_0/L^{up}_0=3.3$ and L_0/L_2 suppression is higher 20/2.5=8 times for pol. beams.

Discussion, conclusion

Polarized RF-guns

Having polarized RF guns with emittances similar to existing unpolarized guns we could obtain the $\gamma\gamma$ luminosity ~10 times higher than that with ILC DRs (all polarization characteristics are similar).

Unpolarized RF-guns

Already with existing RF guns we can dream on the $\gamma\gamma$ luminosity higher than with DR by a factor of $10/F_{pol.ench..}$, where $F_{p.e.}$~2.2-3.3 for 2E=200-500 GeV. The $\gamma\gamma$ luminosity will be about ~3-4 times higher than with DR, but L_0/L_2 in the high energy peak will be only 3.5-2.5 instead of 20 for polarized beams, which is acceptable (the case of H(120) should be checked).

Possible technical problems in suggested technique

1. Dilution of the emittance due to wakefields in combiner sections.
2. All parameters of beamlines should be continuously adjusted in order to combine all 64 bunches to the same phase space (except energy).

The above dreams should be proved by realistic consideration-optimization.