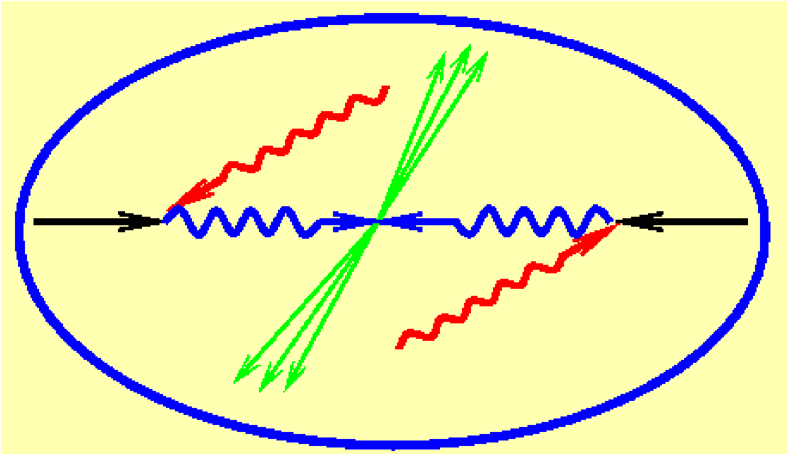

View on photon colliders at ILC, CLIC, Higgs factory SAPPHIRE and super $\gamma\gamma$ factory

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Introduction

Hi Valery,

By the way, recently some DESY colleagues told me that a few years ago there had been a study on the physics case for a gamma-gamma collider, led by former KEK director Sugawara san, and the result of this study was that there is no physics case. According to these sources even you have agreed that there is no physics case for a gamma-gamma collider. Is this correct?

Best regards Xxxxxxxxxx

The answer

Indeed, in 2008 H. Sugawara suggested to build γγ collider for the Higgs study on the energy 2E=160 GeV, as a precursor to the e+e- ILC, because it is cheaper (lower energy, no DR).

The ILCSC asked my opinion. It was (shortly) the following:

Such PLC will be not much cheaper, because needs DR and laser system. The Higgs decay modes, even invisible, can be studied much better in e+e→ZH at 2E~230 GeV due to lower physics backgrounds.

This opinion was confirmed by physics and accelerator groups, followed by corresponding ILCSC statement

… A 180 GeV gamma-gamma precursor would cost about half that of the 500 GeV ILC, but would produce much less physics. A better alternative for early Higgs studies would be a ~ 230 GeV e+e- collider for studying the Higgs through ZH production; this would be ~ 30% more costly than the gamma-gamma collider. ILCSC decided not to pursue the gamma-gamma collider further at this time.

So, ILCSC has not supported PLC as precursor to the ILC, but not PLC in general. PLC is very natural and cheap addition to any LC, has very rich physics program complementary to e+e- collider.

Physics motivation for PLC

(independent on physics scenario)

(shortly)

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

1. the energy is smaller only by 10-20%
2. the number of 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
5. different type 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 rather small additional investments

Photon collider at ILC

The photon collider at ILC (TESLA) has been developed in detail at conceptual level, all simulated, all reported and published (TESLA TDR, etc).

The conversion region: optimization of conversion, laser scheme (optical cavity).

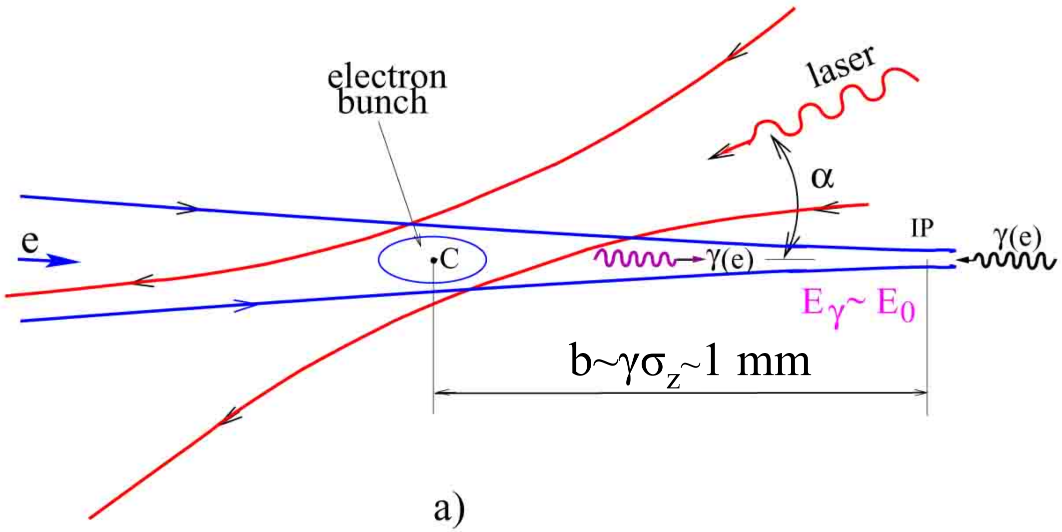
The interaction region: luminosity spectra and their measurement, optimization of luminosity, stabilization of collisions, removal of disrupted beams, crossing angle, beam dump, backgrounds.

The laser scheme (optical cavity) was considered by experts, there is no stoppers, LLNL has all technologies to build the required laser system. Required laser technique is developed independently for many other applications based on Compton scattering.

All special requirements to the ILC design have been formulated and reported to the GDE.

Further developments need political decisions and finances.

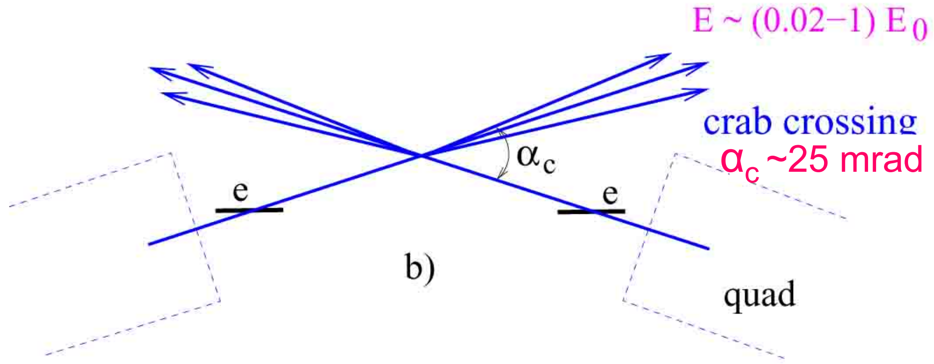
Scheme of $\gamma\gamma$, γe collider



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

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

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



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

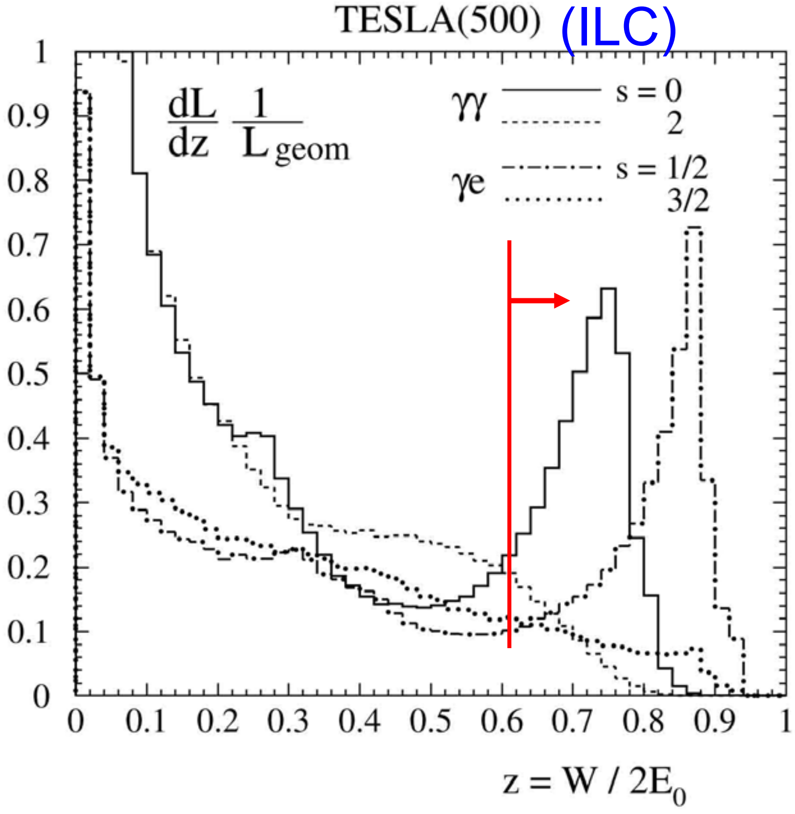
$\omega_{max} \sim 0.8\ E_0$

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

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

(with account multiple Compton scattering, beamstrahlung photons and beam-beam collision effects)

(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 ILC conditions

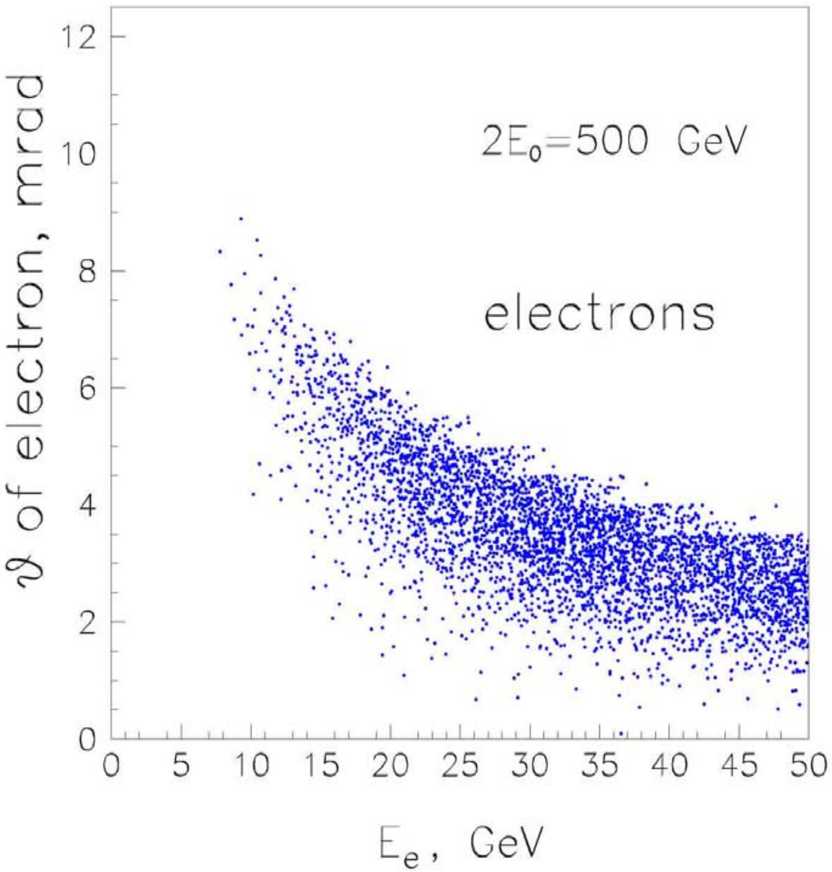
$L_{\gamma\gamma}(z>0.8z_m) \sim (0.17\text{-}0.55)\ L_{e+e-}(\text{nom})$
$\sim (0.35\text{-}1) \cdot 10^{34}\ \text{cm}^{-2}\ \text{s}^{-1}$

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

First number - nominal beam emittances
Second - optimistic emittances
(possible, needs optimization of DR for $\gamma\gamma$)

For γe it is better to convert only one electron beam, in this case it will be easier to identify γe reactions, to measure its luminosity (and polarization) and the γe luminosity will be larger.

Properties of the beams after CP,IP



Electrons:

E_{min}~6 GeV,
$\theta_{x\ max}$~8 mrad
$\theta_{y\ max}$~10 mrad

practically same for
E_0=100 and 250 GeV

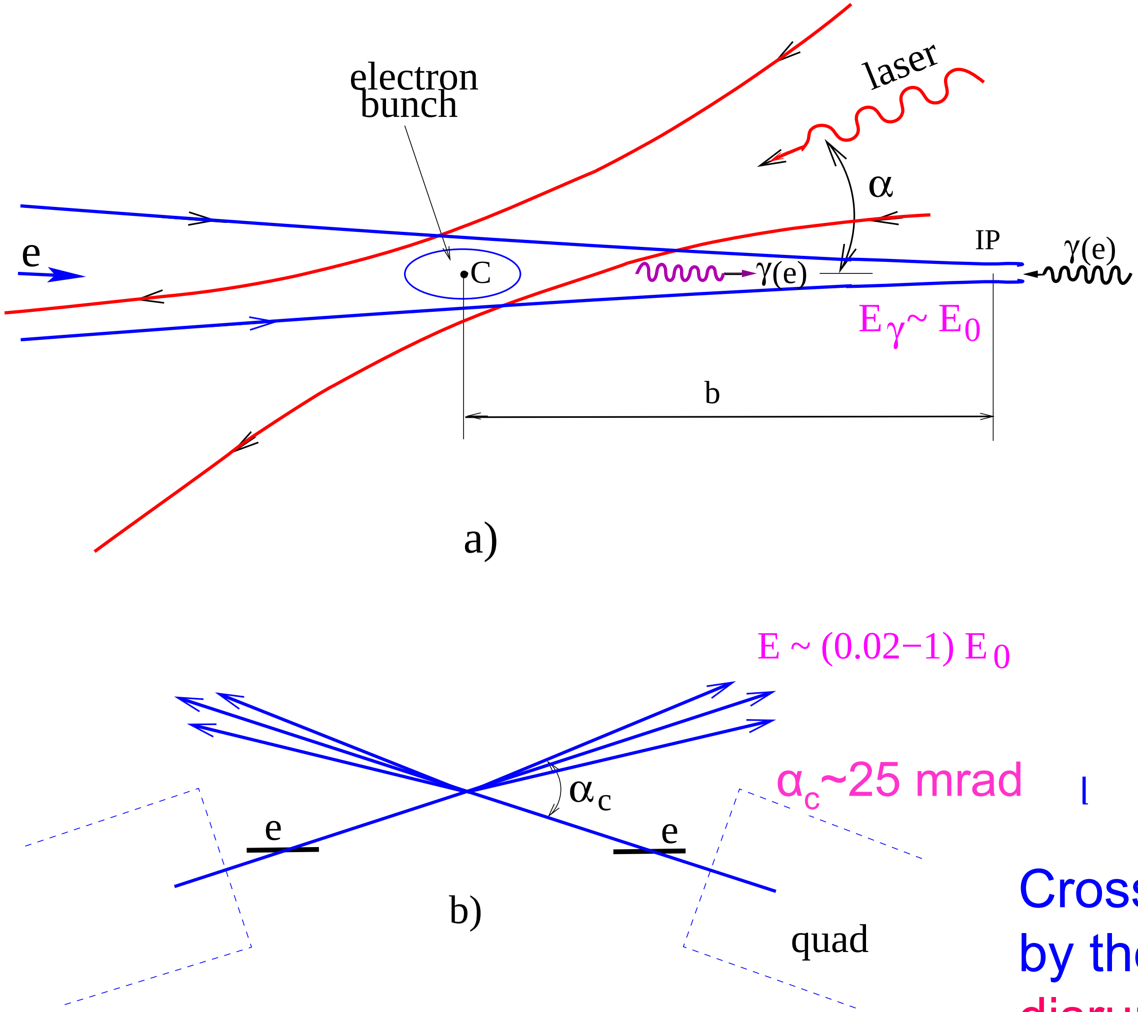
For low energy particles the deflection in the field of opposing beam

$$\vartheta \propto 1/\sqrt{E\sigma_z}$$

An additional vertical deflection, about ±4 mrad, adds the detector field

$$\alpha_c = (5/400)\ (\text{quad}) + 12.5 \cdot 10^{-3} (\text{beam}) \sim 25\ \text{mrad}$$

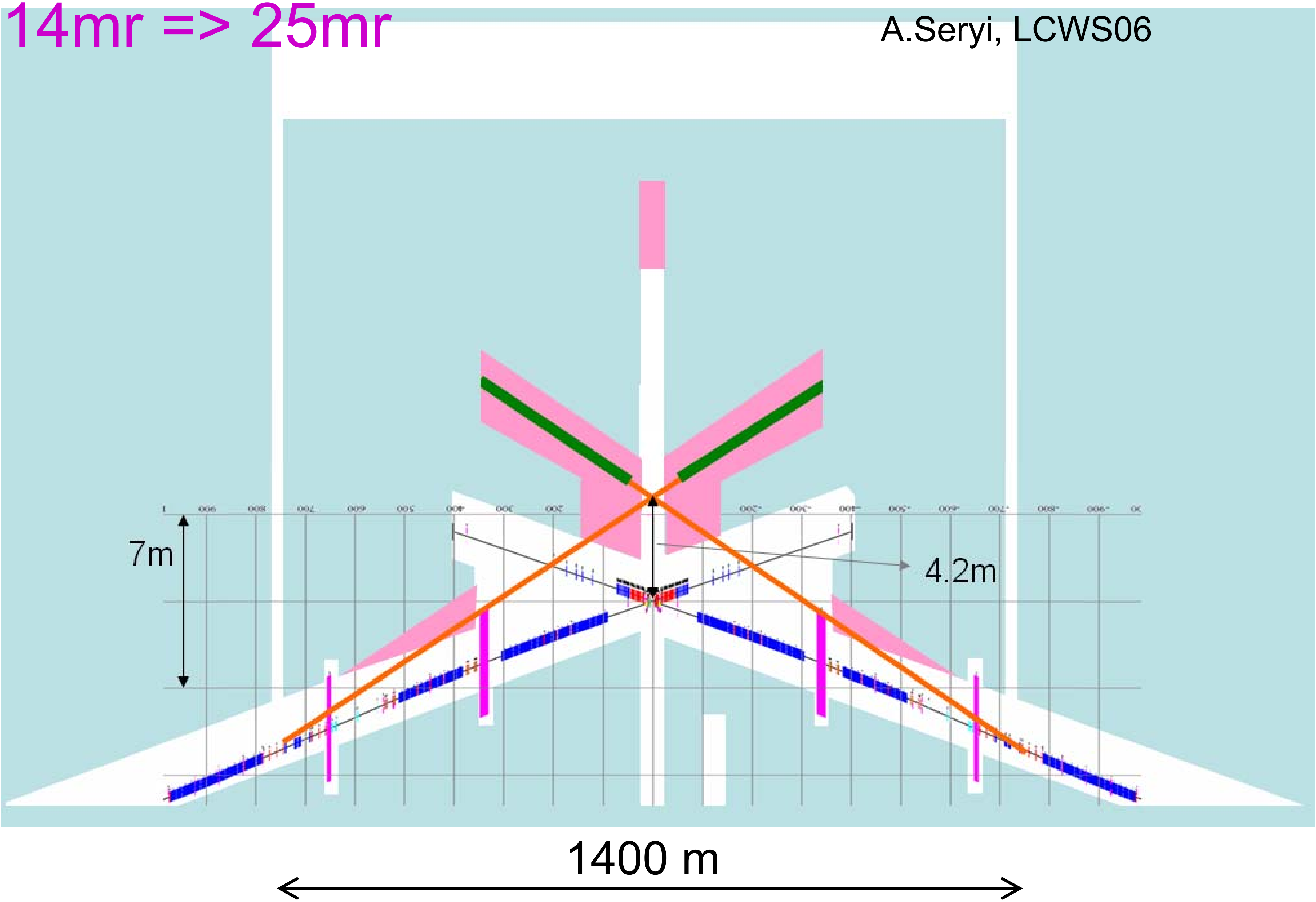
Crab-crossing angle



Crossing angle is determined by the angular spread in the disrupted beam and the radius of the first quad

14mr => 25mr

A.Seryi, LCWS06



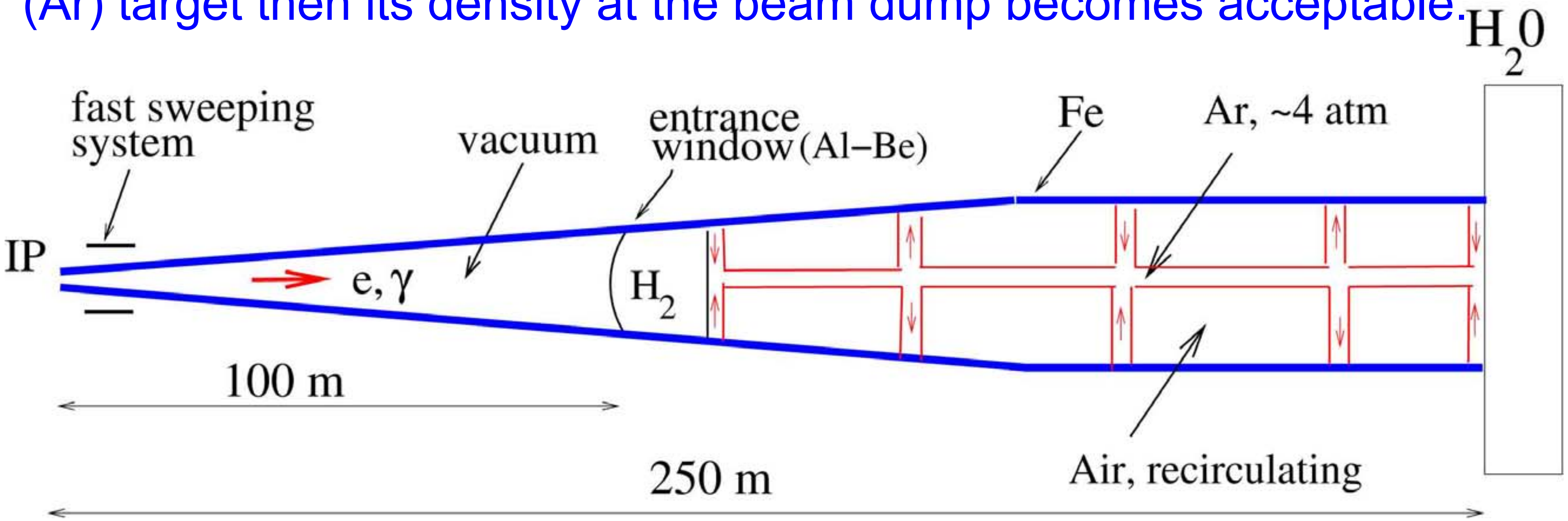
- add. angle is 5.5mrad and detector need to move by about 3-4m

The beam dump

The angular distribution of photons after Compton scattering is very narrow, equal to the angular divergence of electron beams at the IP:

$\sigma_{\theta x} \sim 4\cdot10^{-5}$ rad, $\sigma_{\theta y} \sim 1.5\cdot10^{-5}$ rad, that is 1 x 0.35 cm^2 and beam power about 10 MW at the beam dump. No one material can withstand with such average power and energy of one ILC train.

Possible solution: the photon beam produces a shower in the long gas (Ar) target then its density at the beam dump becomes acceptable.



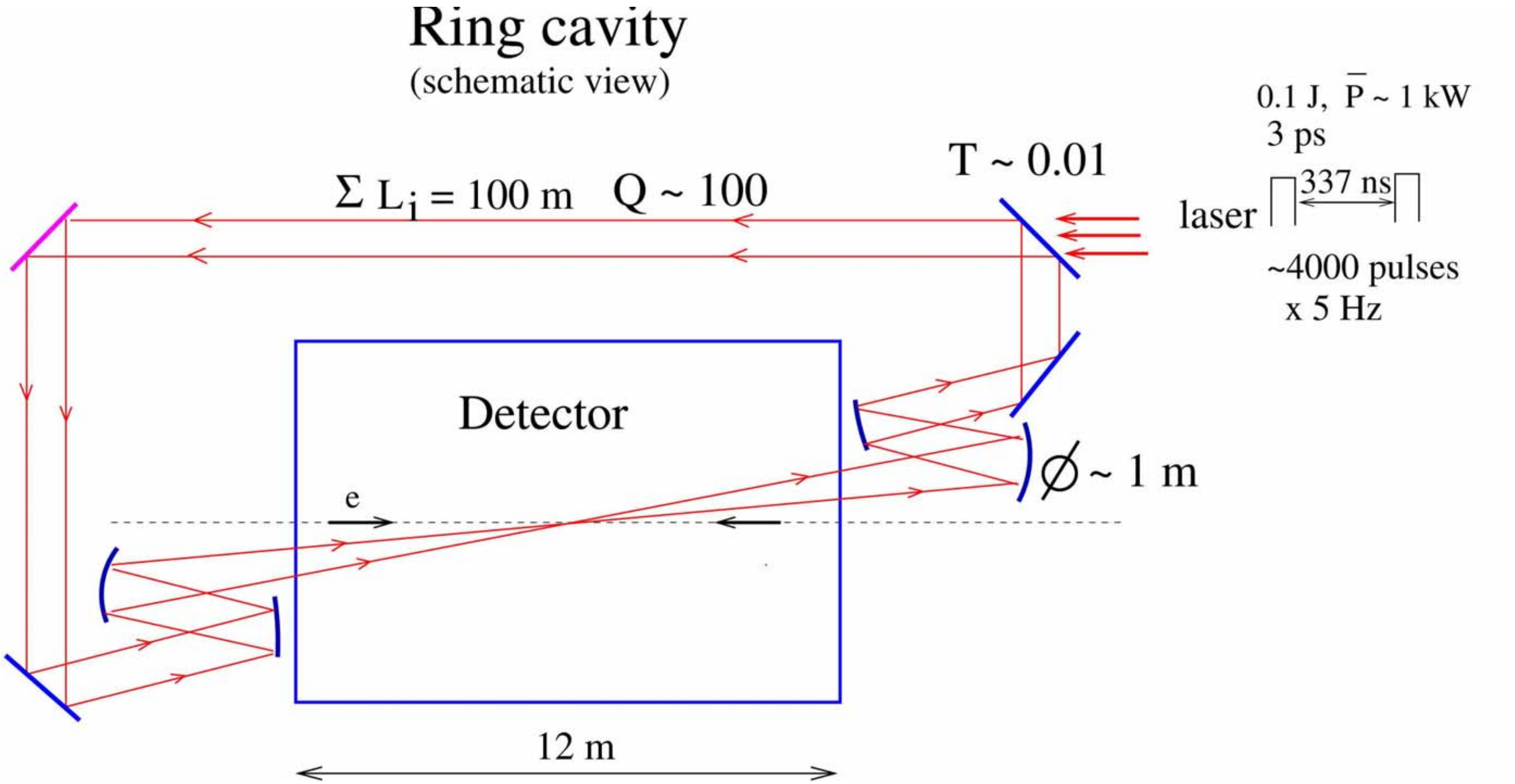
Requirements for laser

Wavelength	~1 μm (good for $2E<0.8$ TeV)
Time structure	$\Delta ct \sim 100$ m, 3000 bunch/train, 5 Hz
Flash energy	~5-10 J
Pulse length	~1-2 ps

If a laser pulse is used only once, the average required power is $P \sim 150$ 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.

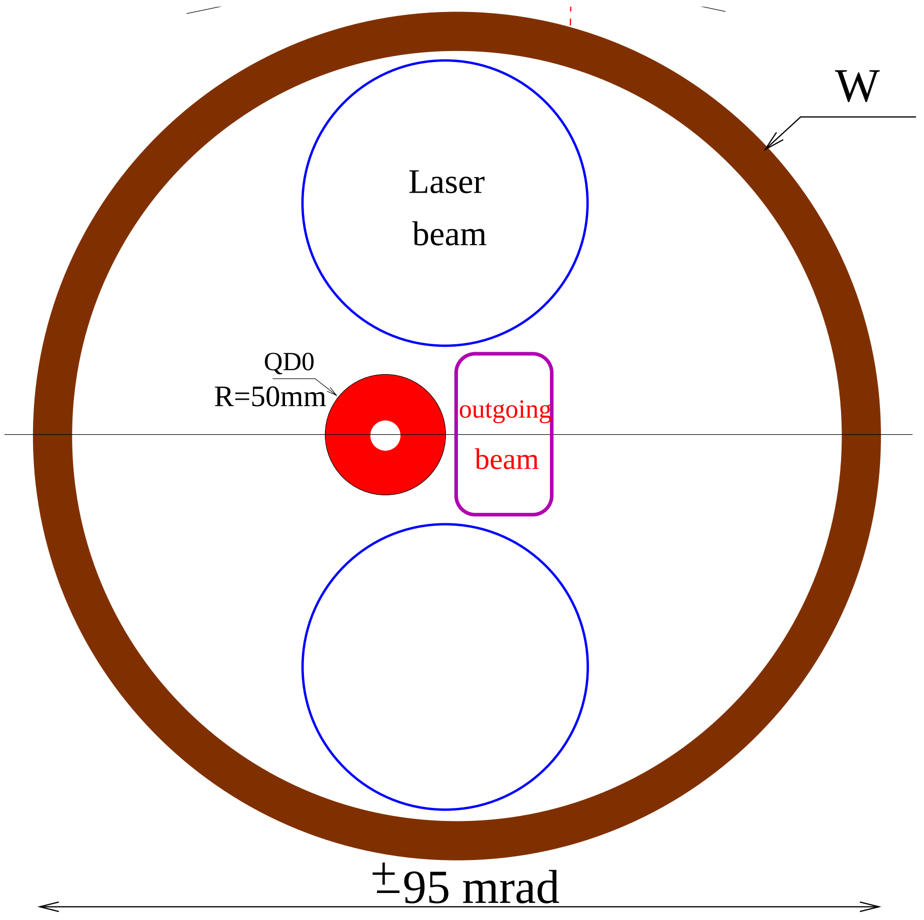
The best is the scheme with accumulation of very powerful laser bunch is an external optical cavity. The pulse structure at ILC (3000 bunches in the train with inter-pulse distance ~100 m) is very good for such cavity. It allows to decrease the laser power by a factor of 100-300, but even in this case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

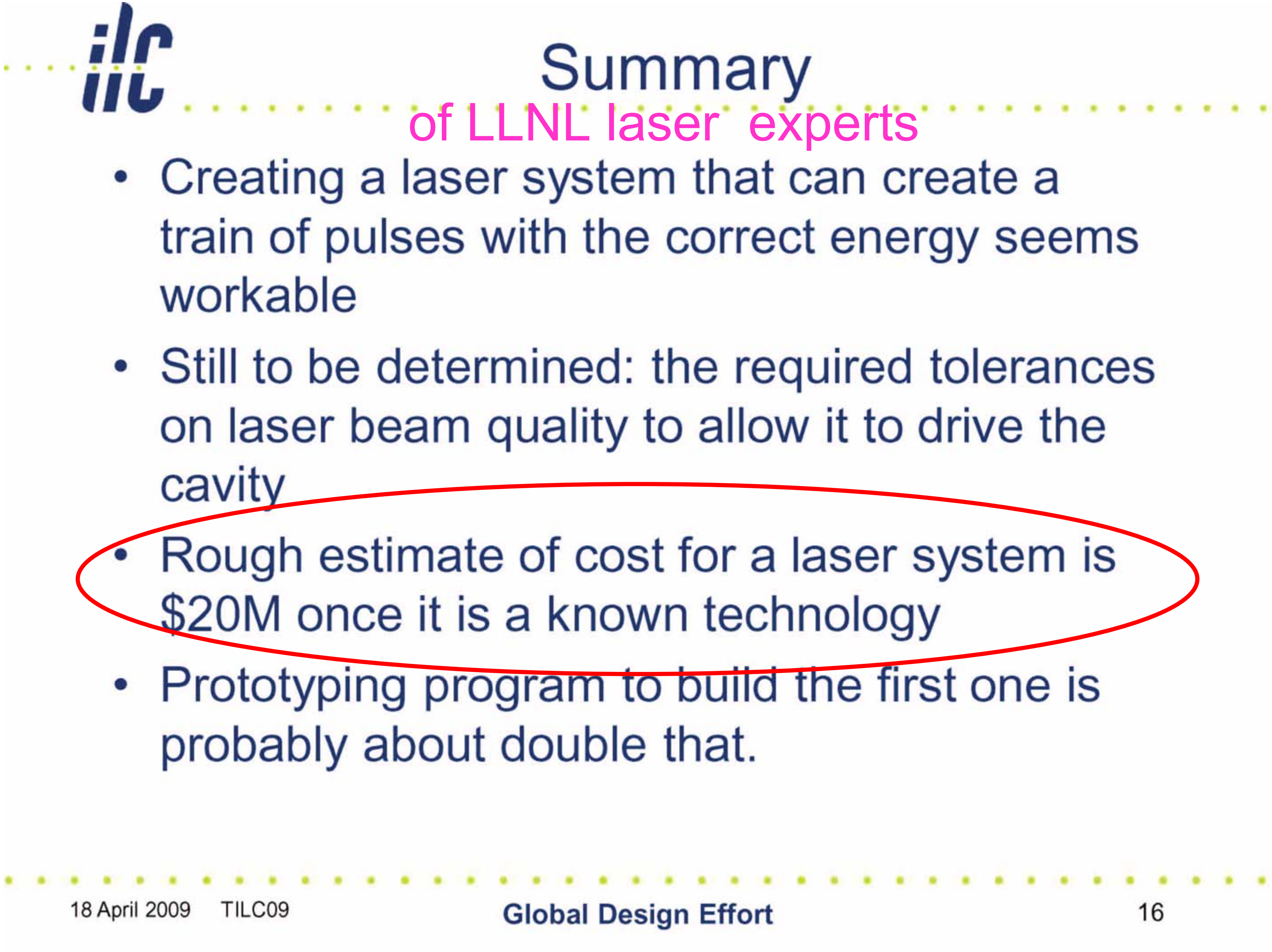
Laser system



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

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





Summary

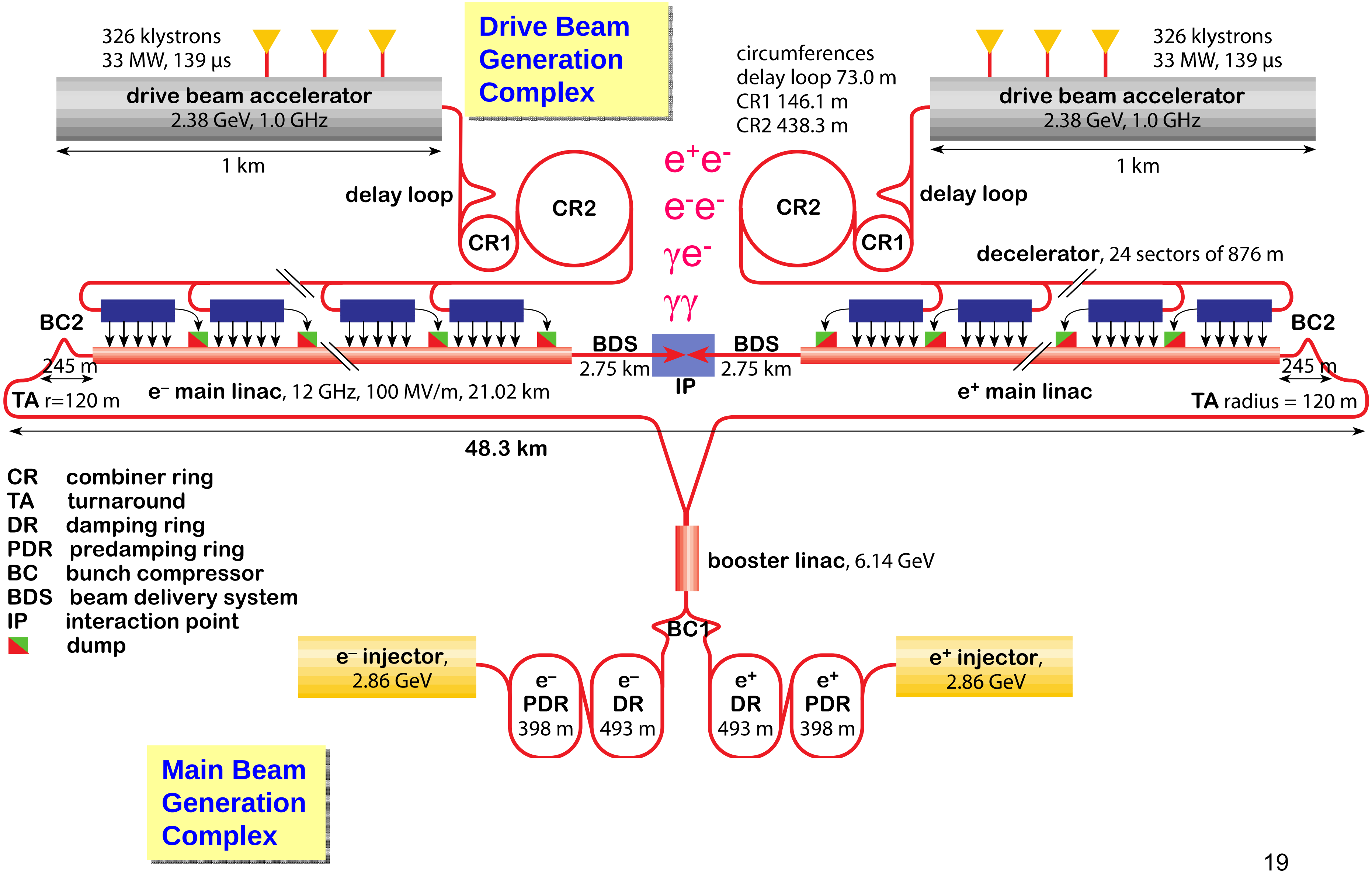
of LLNL laser experts

- Creating a laser system that can create a train of pulses with the correct energy seems workable
- Still to be determined: the required tolerances on laser beam quality to allow it to drive the cavity
- Rough estimate of cost for a laser system is $20M once it is a known technology
- Prototyping program to build the first one is probably about double that.

18 April 2009 TILC09 **Global Design Effort** 16

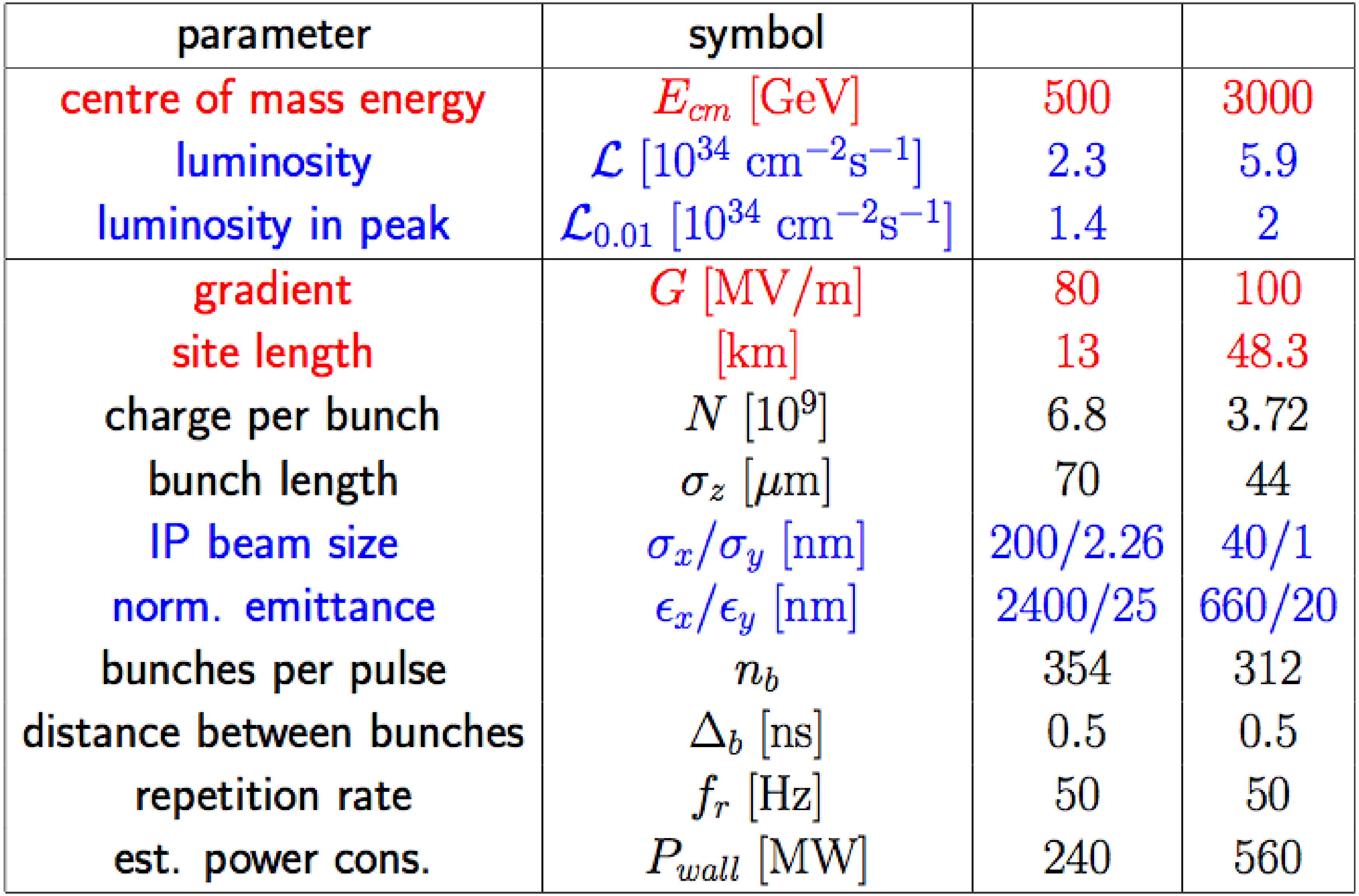
Photon collider at CLIC

The CLIC Layout



CR	combiner ring
TA	turnaround
DR	damping ring
PDR	predamping ring
BC	bunch compressor
BDS	beam delivery system
IP	interaction point
🟥	dump

CLIC main parameters



parameter	symbol		
centre of mass energy	E_{cm} [GeV]	500	3000
luminosity	$\mathcal{L}$ [10^{34} cm^{-2}s^{-1}]	2.3	5.9
luminosity in peak	$\mathcal{L}_{0.01}$ [10^{34} cm^{-2}s^{-1}]	1.4	2
gradient	G [MV/m]	80	100
site length	[km]	13	48.3
charge per bunch	N [10^9]	6.8	3.72
bunch length	σ_z [μm]	70	44
IP beam size	σ_x/σ_y [nm]	200/2.26	40/1
norm. emittance	ϵ_x/ϵ_y [nm]	2400/25	660/20
bunches per pulse	n_b	354	312
distance between bunches	Δ_b [ns]	0.5	0.5
repetition rate	f_r [Hz]	50	50
est. power cons.	P_{wall} [MW]	240	560

Comparison of ILC and CLIC parameters (important for PLC)

Laser wave length $\lambda \propto E$

for ILC(250-500) λ~1μm, for CLIC(250-3000) λ~ 1 - 4.5 μm

Disruption angle $\theta_d \sim (N/\sigma_z E_{min})^{1/2}$

For CLIC angles θ_d is larger on 20%, not important difference.

Laser flash energy A~10 J for ILC, A~5J for CLIC

Duration of laser pulse τ~1.5 ps for ILC, τ~1.5 ps for CLIC

Pulse structure

ILC Δct~100 m, 3000 bunch/train, 5 Hz (f_{col}~15 kH)

CLIC Δct~0.15 m, ~300 bunch/train, 50 Hz (f_{col}~15 kH)

Laser system ILC – a ring optical cavity with Q>100

CLIC –one pass system

(or short linear cavity?)

Laser system for CLIC (V.Telnov, IWLC, CERN, 2010)

Requirements to a laser system for a photon collider at CLIC

Laser wavelength	~ 1 µm
Flash energy	A~5 J
Number of bunches in one train	354
Length of the train	177 ns=53 m
Distance between bunches	0.5 nc
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).

Possible approaches to CLIC laser system

- FELs based on CLIC drive beams.

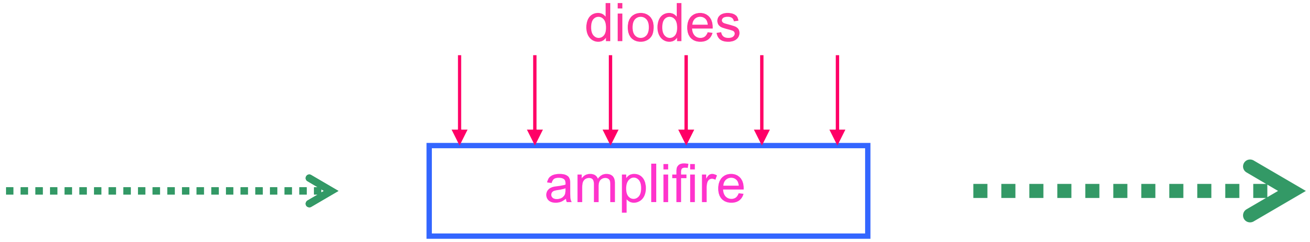
There were suggestions to use CLIC drive beams to generate light flashes (FEL), but they have not enough energy to produce the required flashes energy. In addition, the laser pulse should be several times shorter than the CLIC drive bunch.

For any FEL, the laser power inside 177 ns train should be about 20 GW! While the average power 200 kW. The problem is due to very non uniform pulse structure.

Solid state lasers pumped by diodes.

One can use solid state lasers pumped by diodes. There are laser media with a storage time of about 1 ms. One laser train contains the energy about 5x534=2000 J. Efficiency of the diode pumping about 20%, therefore the total power of diodes should be P~2*2000/0.001/0.20~20 MW. At present the cost of only diodes for the laser system will be ~O(100) M$.

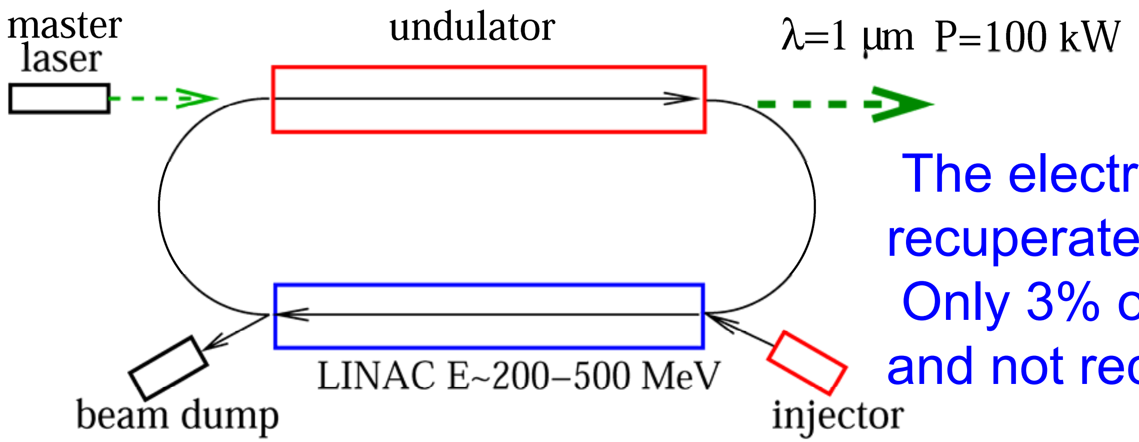
Experts say that such technology will be available in one decade. LLNL works in this direction for laser fusion applications (λ~1μm).



Most power laser systems with diode pumping have wavelength about 1 μm, exactly what is needed for LC(500).

Suggestion:

to use FELs with the energy recuperation instead of diodes for pumping the solid state laser medium.



The electron beam energy can be recuperated using SC linac.

Only 3% of energy is lost to photons and not recuperated.

With recuperation and 10% wall plug RF efficiency the total power consumption of the electron accelerator from the plug will be about 200 kW/ 0.1 = 2 MW only.

The rest past of the laser system is the same as with solid state lasers with diode pumping.

The FEL pumped solid state laser with recuperation of electron beam energy is very attractive approach for short train linear colliders, such as CLIC.

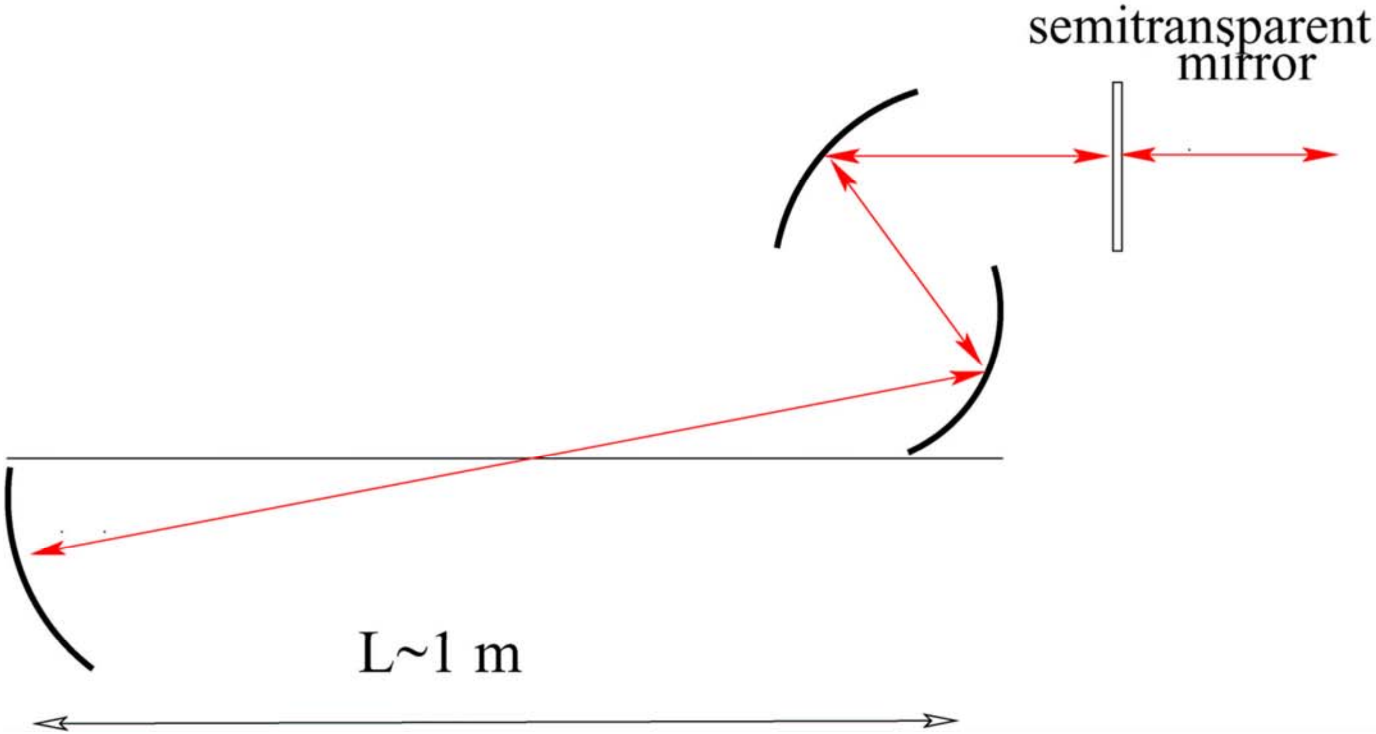
Storage of the pumping energy inside solid-state laser materials reduces the required FEL power inside the CLIC train by a factor 1 ms/ 177 ns=5600!

Such FEL can be built already now.

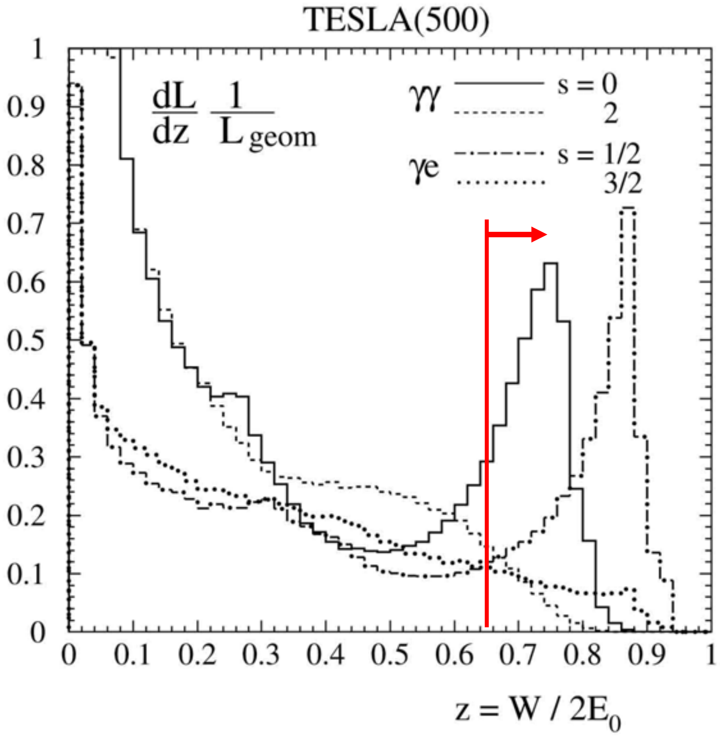
Another option: linear optical cavity

Two mirror cavity is very unstable for small focal sizes, third mirror can reduce requirements to tolerances.

The main problem – very large laser power per cm^2. Divergence of the laser beam is determined by optimum conditions at the laser focus. Larger distance – smaller profit from the cavity: Q~25/L(m). This approach needs careful study.



Luminosity



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

At energies 2E<1 TeV there no collision effects in γγ collisions and luminosity is just proportional to the geometric e-e- luminosity, which can be, in principle, higher than e+e- luminosity.

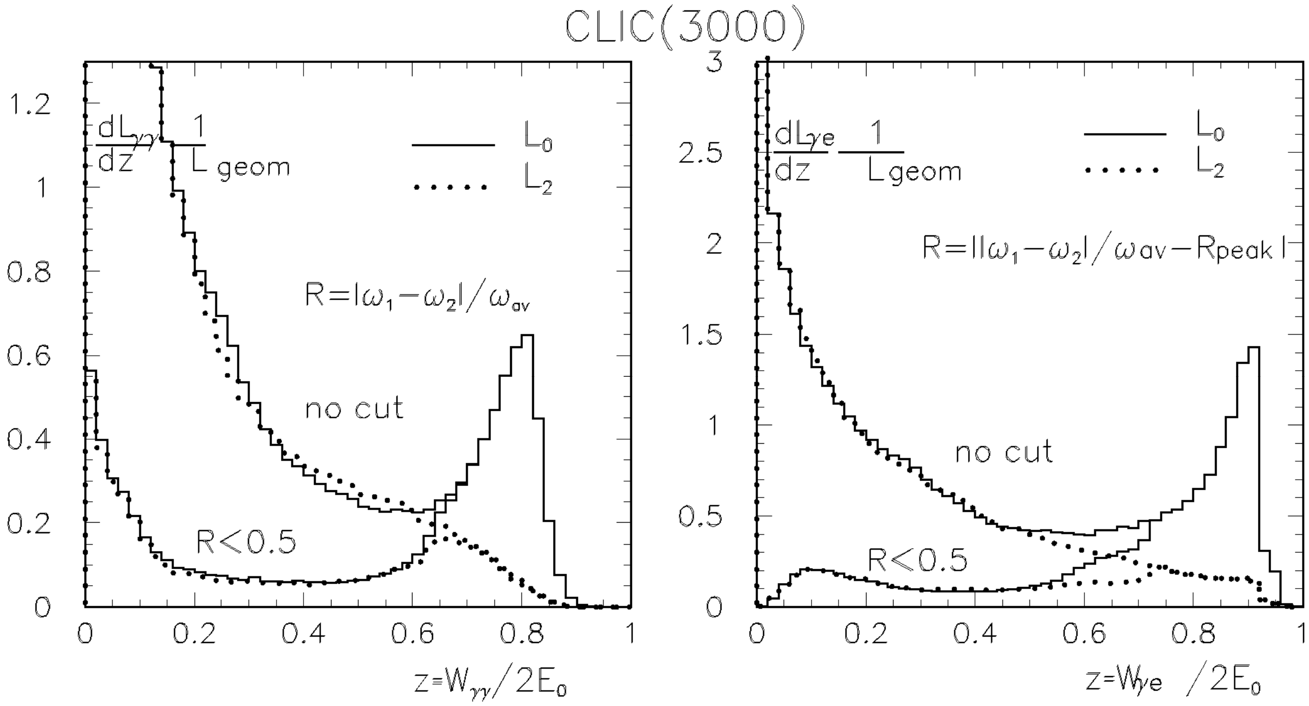
$L_{\gamma\gamma}(z>0.8z_m) \sim 0.1L(e^-e^-,geom)$

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

For CLIC(500) $L_{\gamma\gamma}(z>0.8z_m) \sim 3\cdot10^{33}$ for beams from DR

Luminosity spectra for CLIC(3000)

Here the $\gamma\gamma$ luminosity is limitted by coherent pair creation (the photon is converted to e+e- pair in the field of the opposing beam). The horizontal beam size can be only 2 times smaller than in e+e- collisions.



$L_{\gamma\gamma}(z>0.8z_m) \sim 8\cdot 10^{33}$

Overlap of hadronic events

The typical number of $\gamma\gamma \to$had events per bunch crossing is about 1-2 (both at ILC and CLIC).

However, at CLIC the distance between bunches is very short and many events will overlap. A special detector with time stamps can help but not completely. At ILC the situation is much better.

Note, that in e+e- collisions at CLIC(3000) there are also 2.7 $\gamma\gamma \to$had events per crossing, quite similar to the photon collider.

Photon collider Higgs factory
SAPPHiRE

Submitted to the European Particle Physics Strategy Preparatory Group

SAPPHiRE: a Small $\gamma\gamma$ Higgs Factory

S. A. Bogacz[1], **J. Ellis**[2,3], **L. Lusito**[4], **D. Schulte**[3], **T. Takahashi**[5], **M. Velasco**[4],
M. Zanetti[6] and **F. Zimmermann**[3]

Aug. 2012

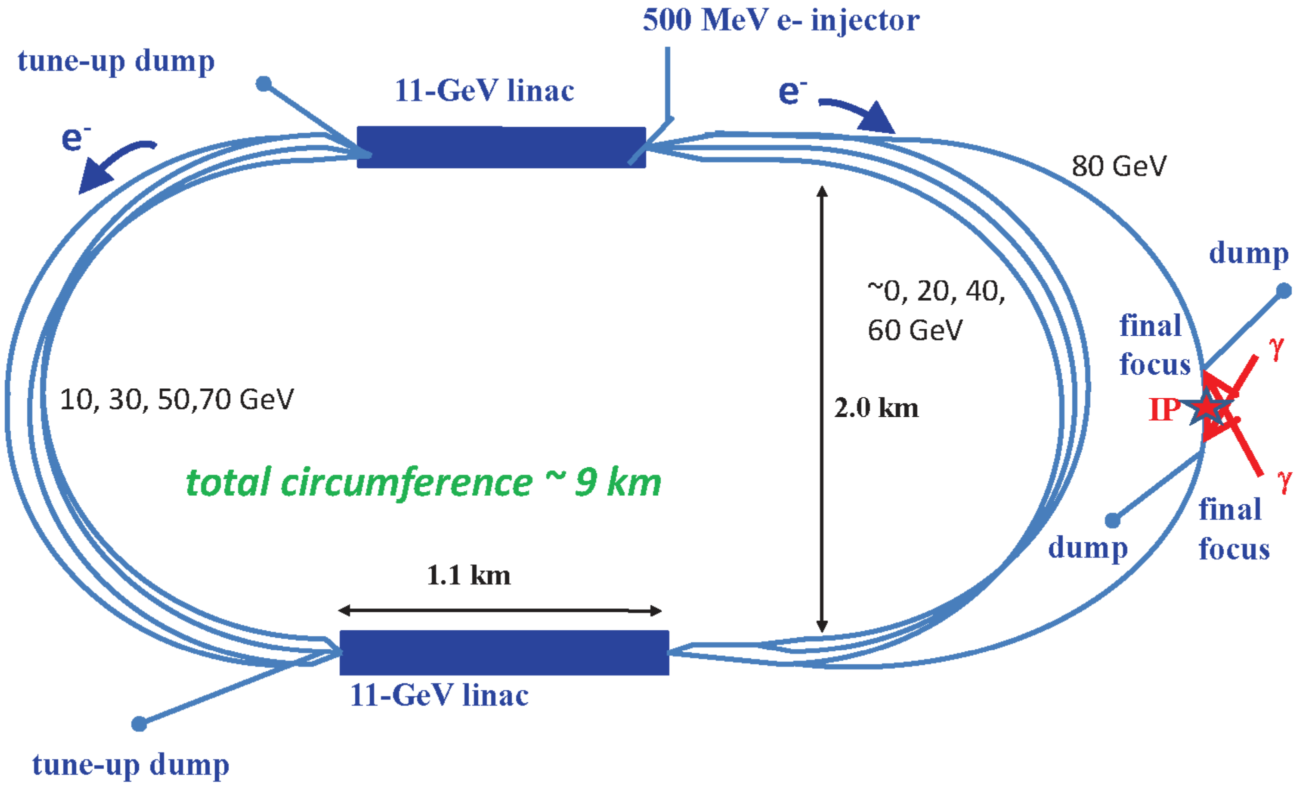


Figure 3: *Sketch of a layout for a $\gamma\gamma$ collider based on recirculating superconducting linacs – the SAPPHiRE concept.*

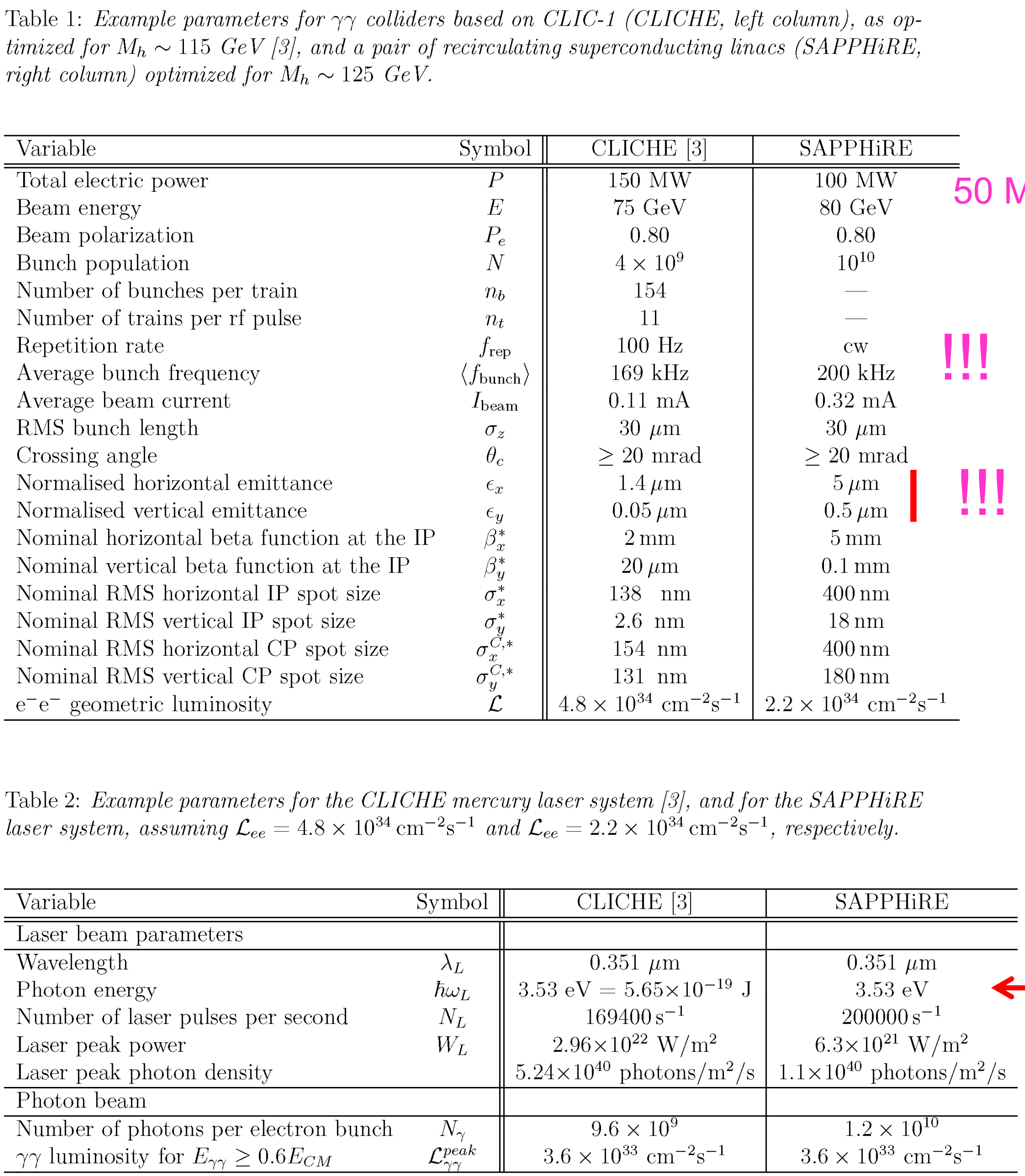


Table 1: *Example parameters for $\gamma\gamma$ colliders based on CLIC-1 (CLICHE, left column), as optimized for $M_h \sim 115$ GeV [3], and a pair of recirculating superconducting linacs (SAPPHiRE, right column) optimized for $M_h \sim 125$ GeV.*

Variable	Symbol	CLICHE [3]	SAPPHiRE
Total electric power	P	150 MW	100 MW
Beam energy	E	75 GeV	80 GeV
Beam polarization	P_e	0.80	0.80
Bunch population	N	4×10^9	10^{10}
Number of bunches per train	n_b	154	—
Number of trains per rf pulse	n_t	11	—
Repetition rate	$f_{\rm rep}$	100 Hz	cw
Average bunch frequency	$\langle f_{\rm bunch} \rangle$	169 kHz	200 kHz
Average beam current	$I_{\rm beam}$	0.11 mA	0.32 mA
RMS bunch length	σ_z	30 μm	30 μm
Crossing angle	θ_c	$\geq$ 20 mrad	$\geq$ 20 mrad
Normalised horizontal emittance	ϵ_x	1.4 μm	5 μm
Normalised vertical emittance	ϵ_y	0.05 μm	0.5 μm
Nominal horizontal beta function at the IP	β_x^*	2 mm	5 mm
Nominal vertical beta function at the IP	β_y^*	20 μm	0.1 mm
Nominal RMS horizontal IP spot size	σ_x^*	138 nm	400 nm
Nominal RMS vertical IP spot size	σ_y^*	2.6 nm	18 nm
Nominal RMS horizontal CP spot size	$\sigma_x^{C,*}$	154 nm	400 nm
Nominal RMS vertical CP spot size	$\sigma_y^{C,*}$	131 nm	180 nm
e$^-$e$^-$ geometric luminosity	$\mathcal{L}$	4.8×10^{34} cm^{-2}s^{-1}	2.2×10^{34} cm^{-2}s^{-1}

Table 2: *Example parameters for the CLICHE mercury laser system [3], and for the SAPPHiRE laser system, assuming $\mathcal{L}_{ee} = 4.8 \times 10^{34}\,$cm^{-2}s^{-1} and $\mathcal{L}_{ee} = 2.2 \times 10^{34}\,$cm^{-2}s^{-1}, respectively.*

Variable	Symbol	CLICHE [3]	SAPPHiRE
Laser beam parameters			
Wavelength	λ_L	0.351 μm	0.351 μm
Photon energy	$\hbar\omega_L$	3.53 eV = 5.65×10^{-19} J	3.53 eV
Number of laser pulses per second	N_L	169400 s^{-1}	200000 s^{-1}
Laser peak power	W_L	2.96×10^{22} W/m^2	6.3×10^{21} W/m^2
Laser peak photon density		5.24×10^{40} photons/m^2/s	1.1×10^{40} photons/m^2/s
Photon beam			
Number of photons per electron bunch	N_γ	9.6×10^9	1.2×10^{10}
$\gamma\gamma$ luminosity for $E_{\gamma\gamma} \geq 0.6 E_{CM}$	$\mathcal{L}_{\gamma\gamma}^{peak}$	3.6×10^{33} cm^{-2}s^{-1}	3.6×10^{33} cm^{-2}s^{-1}

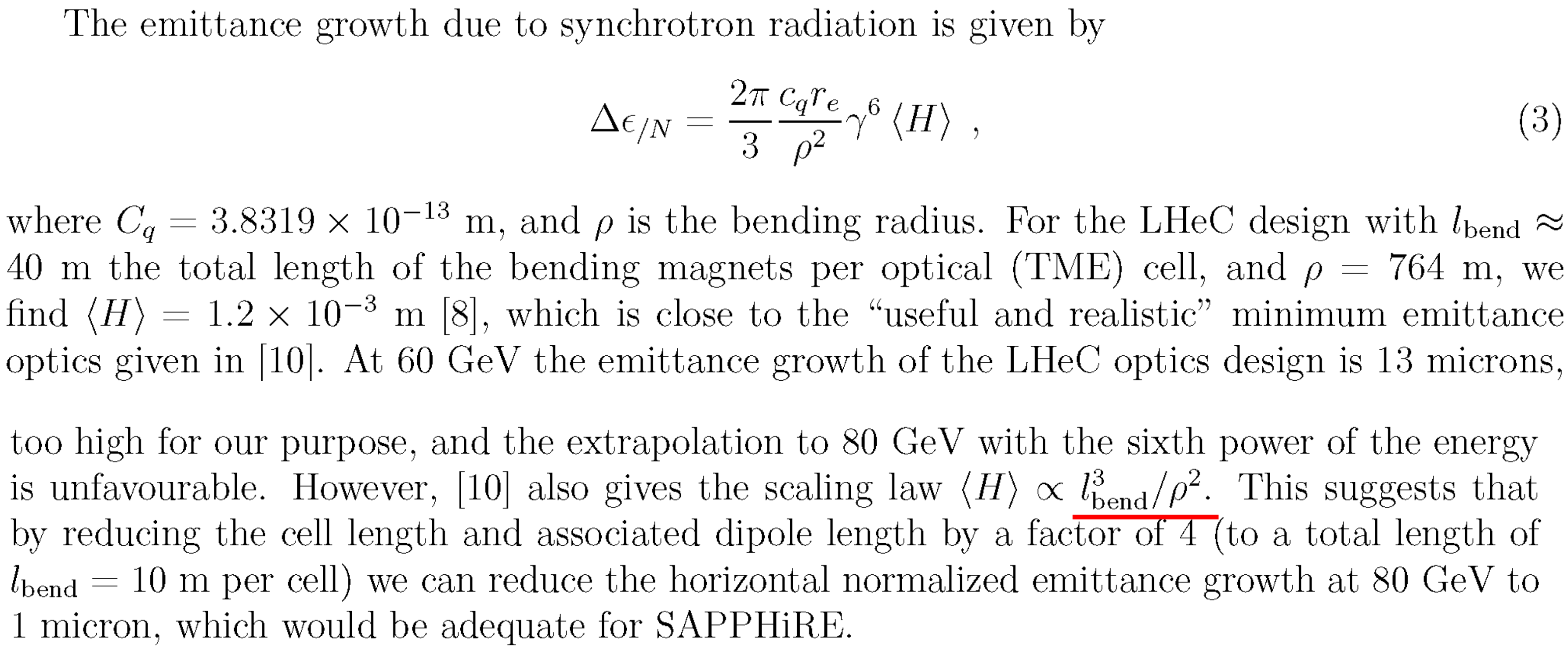
50 MW only beams

!!!

!!!

!

The main problem of the recirculating linac is the increase of the horizontal emittance in arcs



The emittance growth due to synchrotron radiation is given by

$$\Delta\epsilon_{/N} = \frac{2\pi}{3}\frac{c_q r_e}{\rho^2}\gamma^6 \langle H \rangle \ , \tag{3}$$

where $C_q = 3.8319 \times 10^{-13}$ m, and ρ is the bending radius. For the LHeC design with $l_{\mathrm{bend}} \approx 40$ m the total length of the bending magnets per optical (TME) cell, and $\rho = 764$ m, we find $\langle H \rangle = 1.2 \times 10^{-3}$ m [8], which is close to the "useful and realistic" minimum emittance optics given in [10]. At 60 GeV the emittance growth of the LHeC optics design is 13 microns,

too high for our purpose, and the extrapolation to 80 GeV with the sixth power of the energy is unfavourable. However, [10] also gives the scaling law $\langle H \rangle \propto \underline{l_{\mathrm{bend}}^3/\rho^2}$. This suggests that by reducing the cell length and associated dipole length by a factor of 4 (to a total length of $l_{\mathrm{bend}} = 10$ m per cell) we can reduce the horizontal normalized emittance growth at 80 GeV to 1 micron, which would be adequate for SAPPHiRE.

SUPPHIRE needs smaller emittance dilution than in existing designs (LHeC), therefore it was suggested to decrease the dipole section length by a factor of 4 and thus to decrease the dilution by a factor of 64! However, it was not noticed that in this case the quads gradient should be 4^2=16 times larger!

Main critical remarks on SAPPHIRE

1. The emittance dilution in arcs is too optimistic (quad’s gradients are forgotten, not scaled)
2. The initial beam normalized emittances, 5 and 0.5 mm mrad in X and Y directions corresponds to best emittances of unpolarized RF guns. PLC needs polarized electrons. Present polarized DC guns (polarized RF guns do not exist yet) have emittances > 20 times larger! It means that the luminosity will be 20 times smaller. That is why PLC at ILC assumes DR.
3. Conservation of polarization in rings is a problem (due to the energy spread).
4. The length of the ring 9 km (2.2 km linac, 30 km arcs). The LC with G=30 MeV/m would have L=6 km total length (with the final focus) and can work with smaller emittances and thus can have a higher luminosity. Where is profit?
5. It is obvious that e+e- is better for the Higgs study, there is no chance to get support of physics community, if this collider is instead of e+e-(worse that precursor).

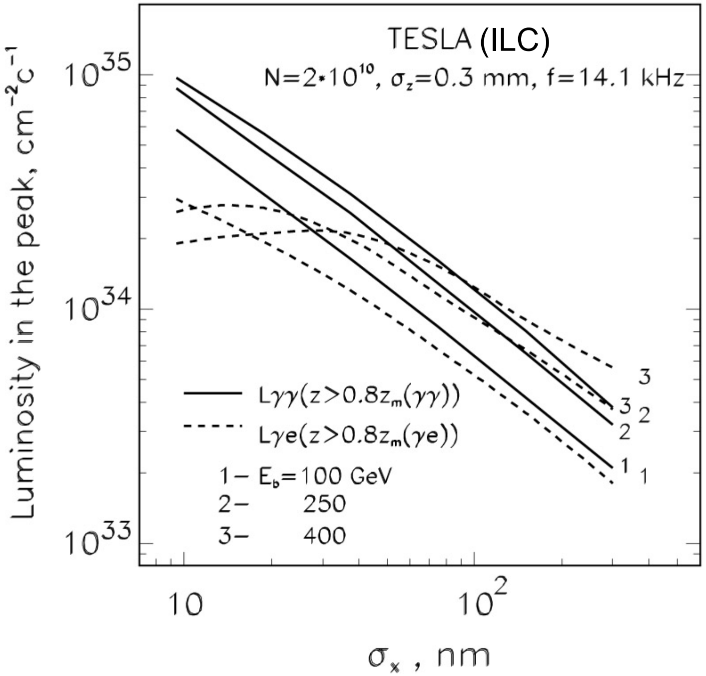
Dreams of γγ factories

Factors limiting $\gamma\gamma$,γe luminosities

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).


Telnov,1998

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 , $\beta_y \sim \sigma_z$

Having electron beams with smaller emittances one could dream on photon colliders with the γγ-luminosity up to $L \sim 10^{35}$ in the high energy peak.

Collision effects do not restrict the luminosity at 2E<1 TeV.

The cross section for the Higgs in γγ is higher than in e+e- by a factor of 5, for any charged pair by a factor of 5-10, so the number of interesting events could be higher by a factor of 20-50 times.

The problem – emittances. Damping rings emittances are already near physics limits (due to SR). RF guns give larger product of horizontal and vertical emittances than DRs (determined by the space charge). Moreover, polarized RF guns do not exist yet.

What are possible ways to small emittances, to PLC without damping rings?

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.

What to do?

Method №1

The most promising way is the laser cooling of electron beams for linear colliders (V.Telnov, 1987). This method allows to reach the desired small transverse emittances and preserves the longitudinal polarization. As injector the DC polarized gun can be used. Progress in laser optical cavities makes the goal more and more realistic. The method needs a more detailed consideration and optimization.

Method №2
(based on longitudinal emittances)

V.Telnov, LWLC10, CERN

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.

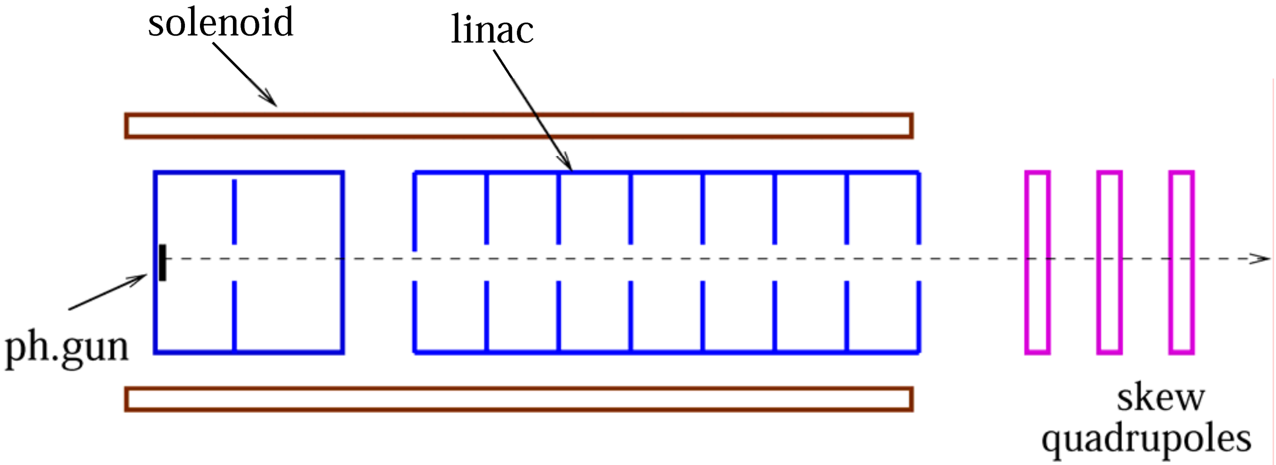
In the CLIC case the distance between bunches is very small therefore micro bunches are produced by many separate photo-guns.

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.



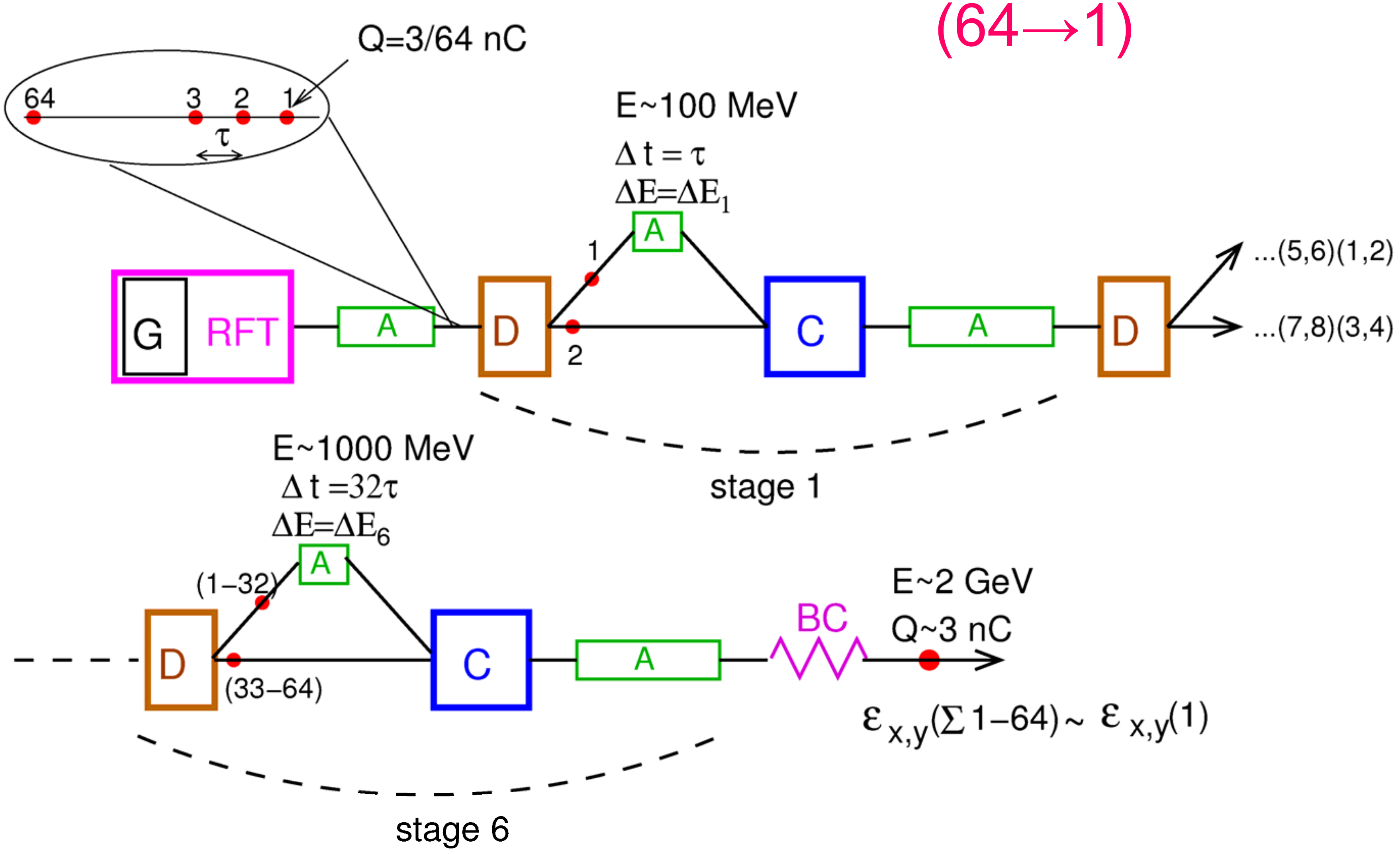
After such transformation $\varepsilon_{nx}\varepsilon_{ny}=\varepsilon^0_{nx}\varepsilon^0_{ny}=(\varepsilon^G_n)^2=\text{const}$

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

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)

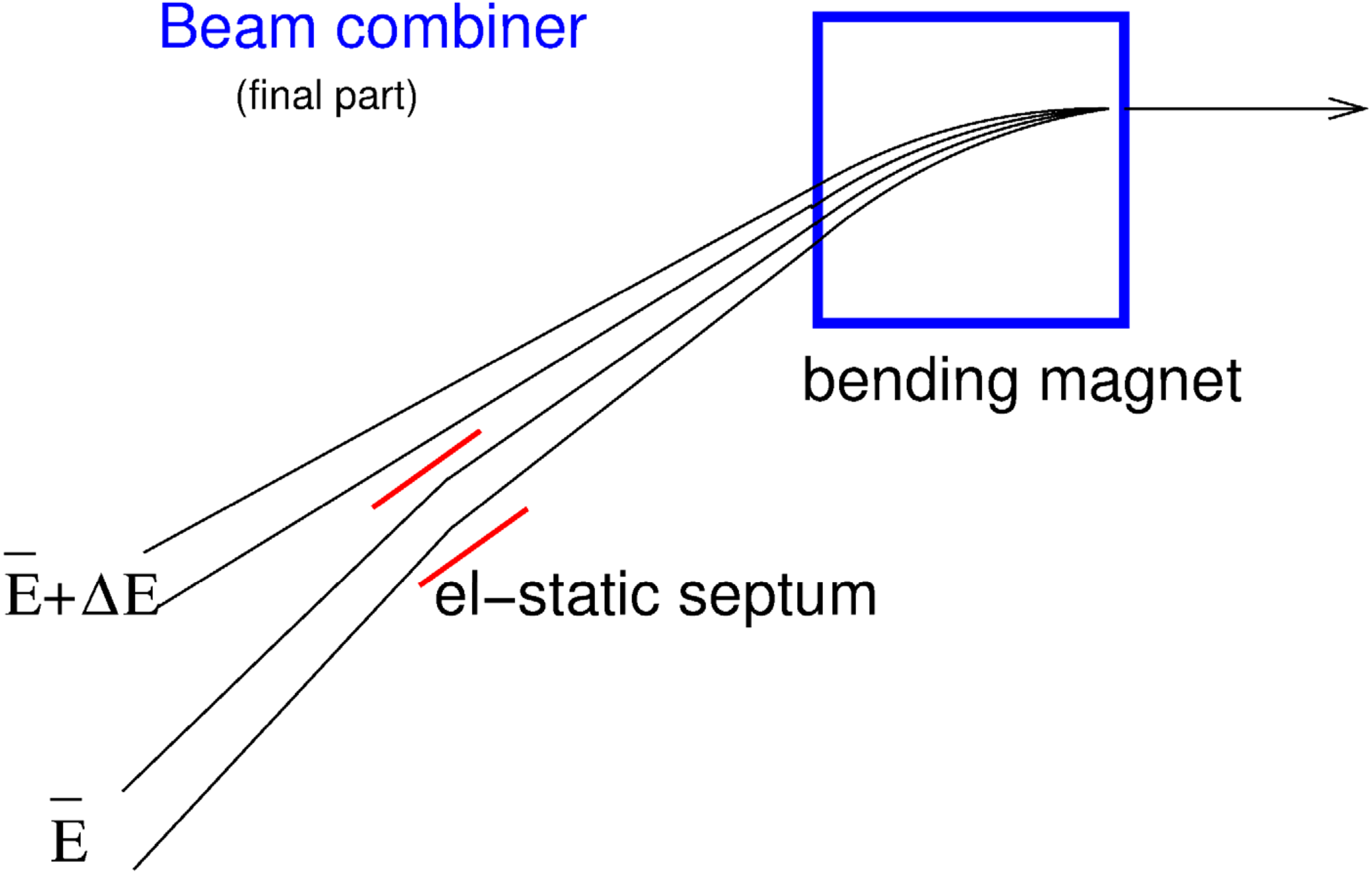


G –photogun, A –RF–cavities (accel), RFT –round to flat transformer,

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.

For more details see the talk at LWLC10.

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

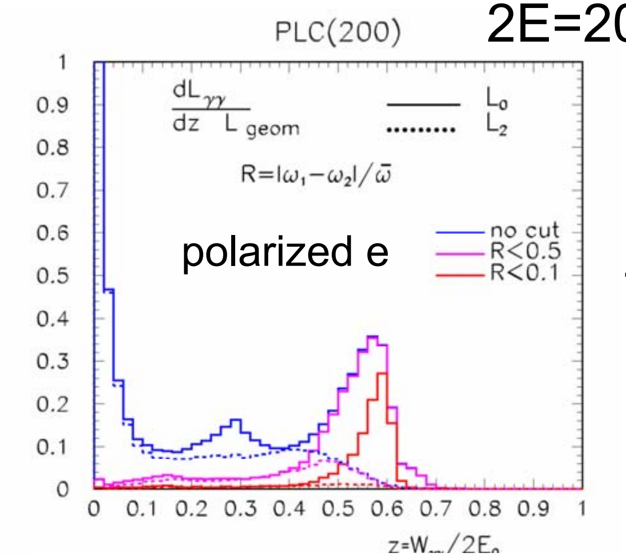
polarized 85%, $\rho=3$
unpolarized, $\rho=3$

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 $\rho=3$).

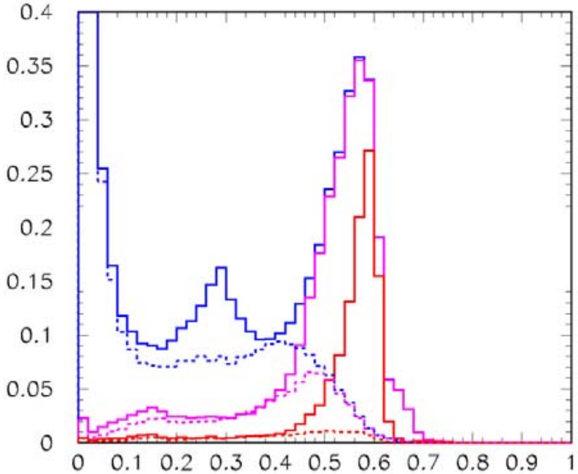
Comparison of polarized and unpolarized electron beams,

2E=200 GeV, ρ=3



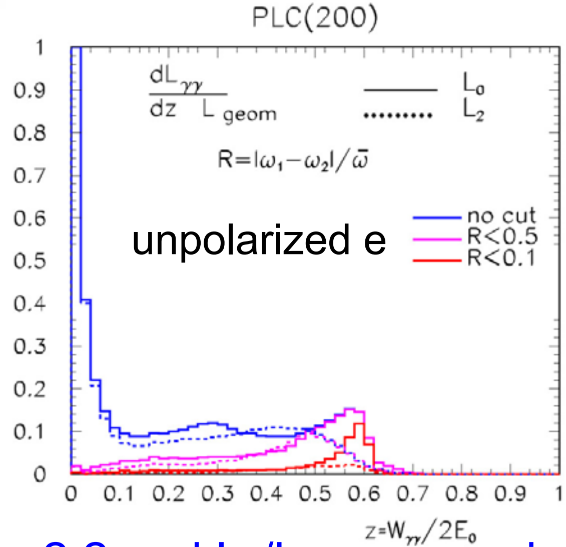
polarized e

zoom →



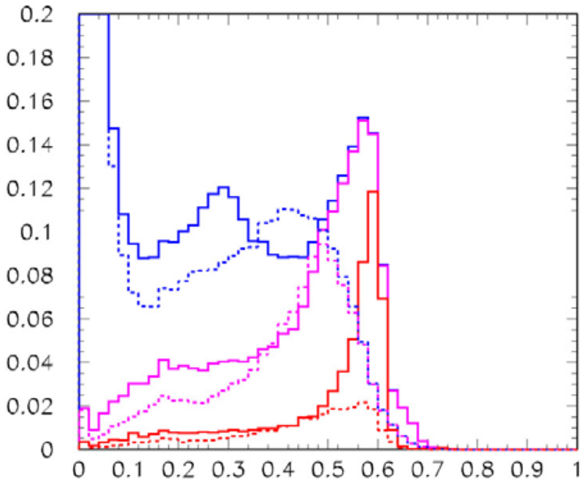
at $z>0.85z_m$

L^p_0/L^p_2~20



unpolarized e

zoom →

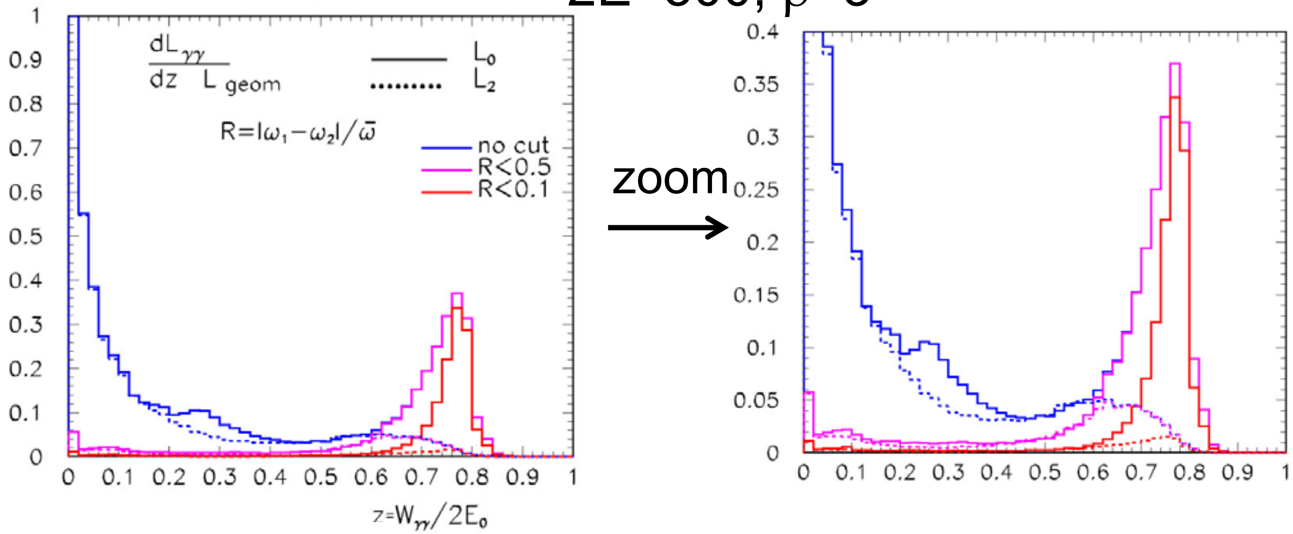


L^{up}_0/L^{up}_2~3.55

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, $\gamma\gamma$ collisions with unpol. electrons have rather good polarization properties, sufficient for study of many processes.

Comparison of polarized and unpolarized electron beams

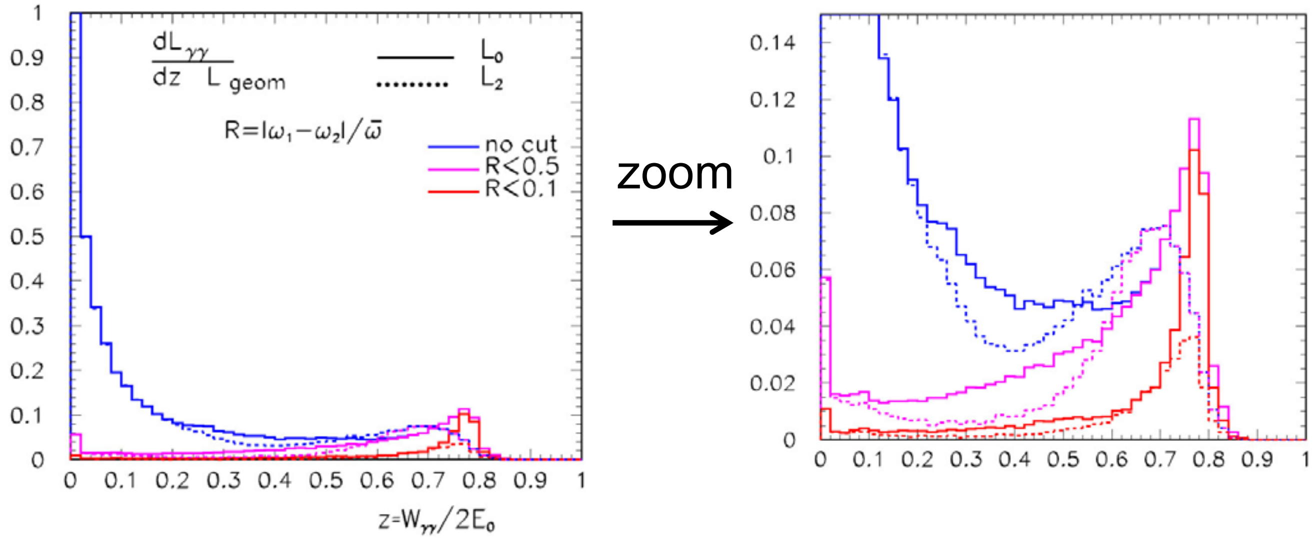
2E=500, ρ=3



zoom

at $z>0.85z_m$

$L^p{}_0/L^p{}_2\sim20$



zoom

$L^{up}{}_0/L^{up}{}_2\sim2.5$

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

Summary on low emittances with guns

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 ideas should be proved by realistic consideration-optimization.

Conclusion

- Photon colliders have sense as a very cost effective addition for e+e- colliders: as the LC second stage or as the second IP (preferable).
- PLC at ILC is conceptually clear, the next step is the design and construction of the laser system prototype.
- PLC at CLIC is more difficult due to much shorter trains. The solution is visible, need a detailed study.
- PLC SAPPHIRE proposal is based on two mistakes, one of them can be corrected by increasing PLC radius, the second can be corrected only by adding damping rings. In any case, the PLC for Higgs without e+e- has not sufficient physics case.
- PLC without damping rings is possible, could have even higher (or much higher) luminosity, needs further study. That could open the way to γγ factories, to precision measurement of the Higgs self coupling etc (if there is any new physics in the sub-TeV region).