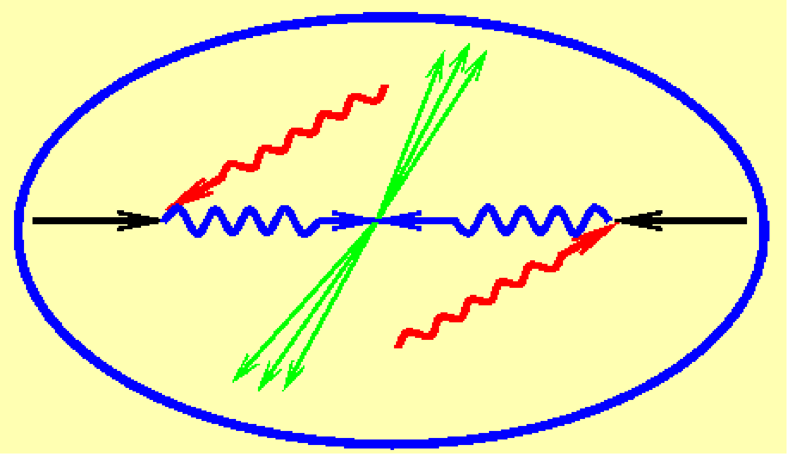

Photon Collider at CLIC

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- Introduction:

  differences between ILC and CLIC
- New approaches to a laser system for CLIC
- Luminosity, etc
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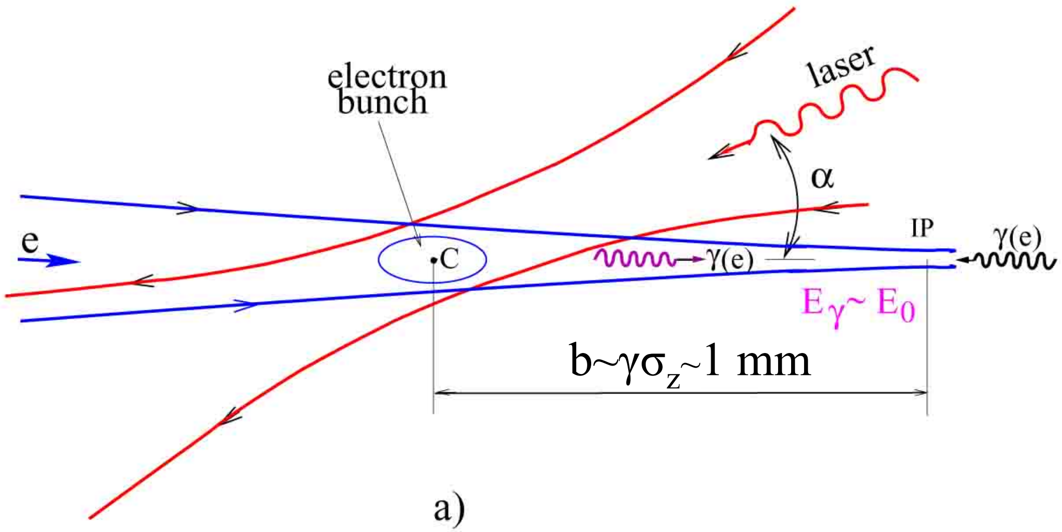
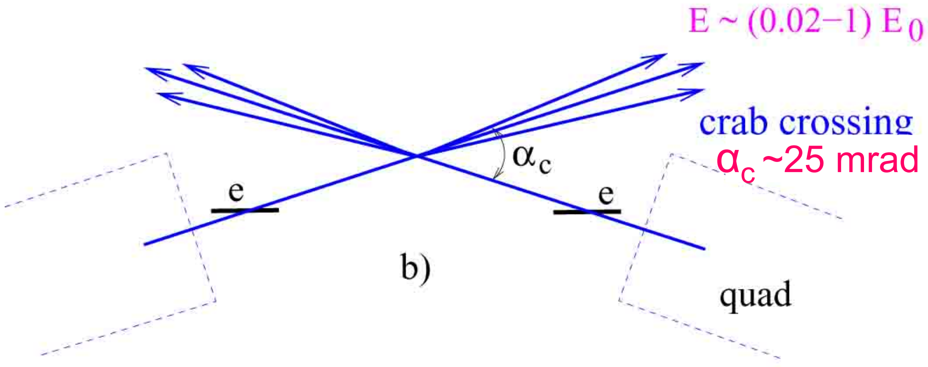
Scheme of $\gamma\gamma$, γe collider



a)



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

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

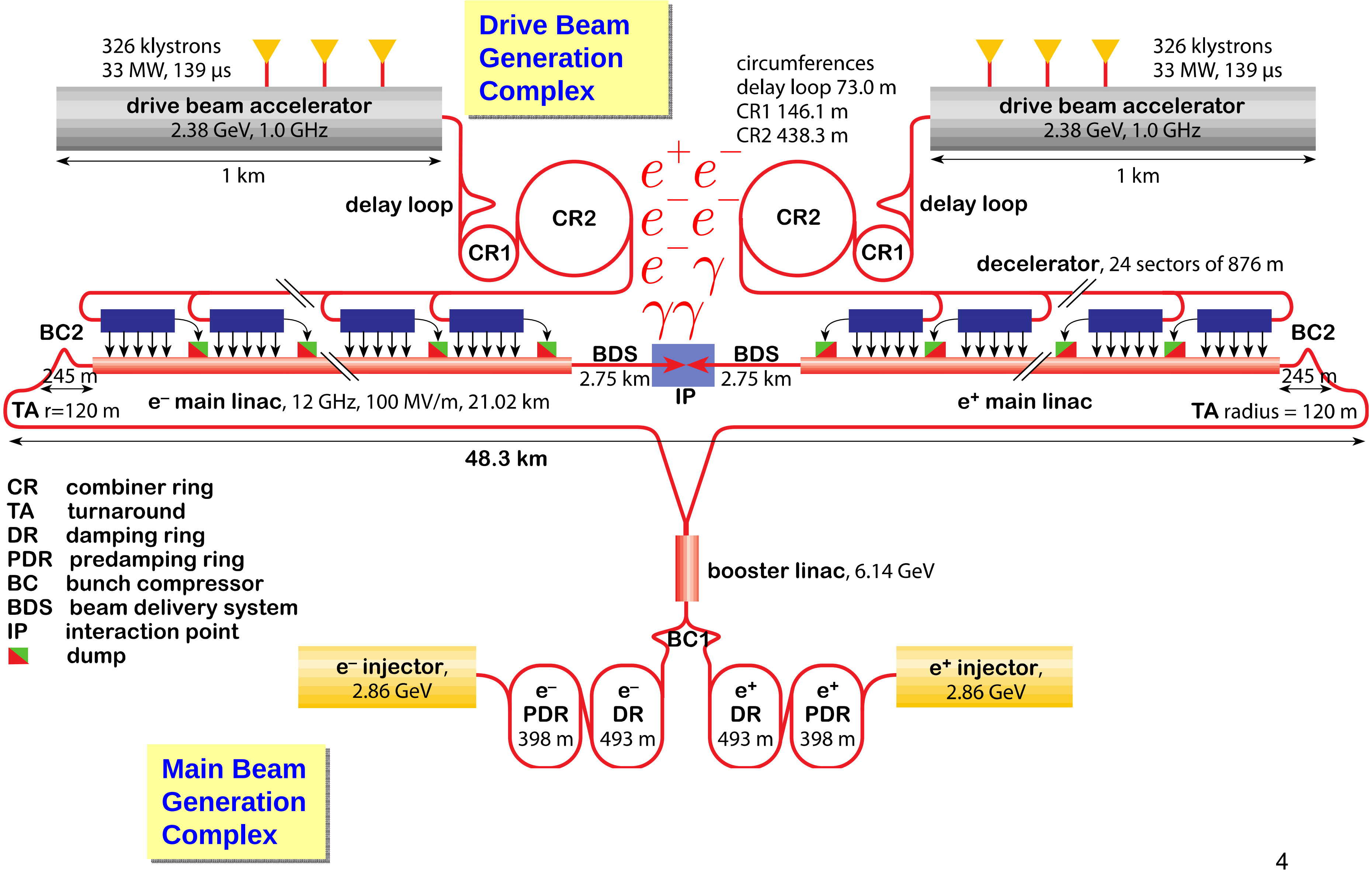
$E_0 = 250$ GeV, $\omega_0 = 1.17$ eV
($\lambda = 1.06$ μm) $\Rightarrow$
x=4.5, ω_m=0.82E_0=205 GeV

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

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

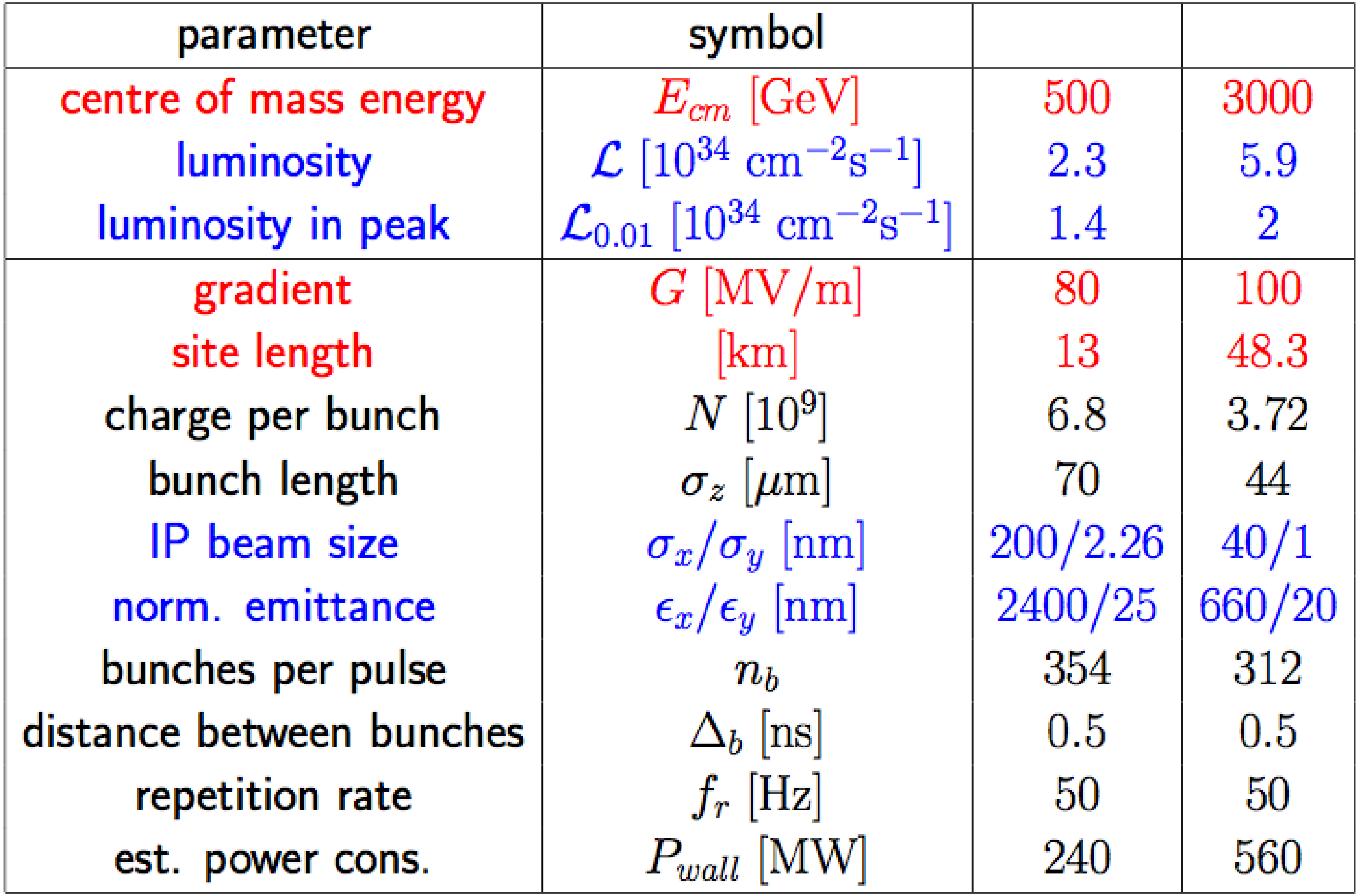
$W_{\gamma\gamma,\,max} \sim 0.8 \cdot 2E_0$
$W_{\gamma e,\,max} \sim 0.9 \cdot 2E_0$

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

+some other parameters

CLIC evolution from 500 GeV to 3 TeV

Center-of-mass energy	CLIC 500 GeV		CLIC 3 TeV	
Beam parameters	Conservative	Nominal	Conservative	Nominal
Accelerating structure	502		G	
Total (Peak 1%) luminosity	$0.9(0.6)\cdot10^{34}$	$2.3(1.4)\cdot10^{34}$	$1.5(0.73)\cdot10^{34}$	$5.9(2.0)\cdot10^{34}$
Repetition rate (Hz)	50			
Loaded accel. gradient (MV/m)	80		100	
Main linac RF frequency (GHz)	12			
Bunch charge (10^9)	6.8		3.72	
Bunch separation (ns)	0.5			
Beam pulse duration (ns)	177		156	
Beam power/beam (MW)	4.9		14	
Hor./vert. norm. emitt ($10^{-6}/10^{-9}$)	3/40	2.4/25	2.4/20	0.66/20
Hor/Vert FF focusing (mm)	10/0.4	8 / 0.1	8 / 0.3	4 / 0.07
Hor./vert. IP beam size (nm)	248 / 5.7	202 / 2.3	83 / 2.0	40 / 1.0
Hadronic events/crossing at IP	0.07	0.19	0.57	2.7
Coherent pairs at IP	10	100	$5\ 10^7$	$3.8\ 10^8$
BDS length (km)	1.87		2.75	
Total site length km	13.0		48.3	
Wall plug to beam transfer eff	7.5%		6.8%	
Total power consumption (MW)	129.4		415	

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)

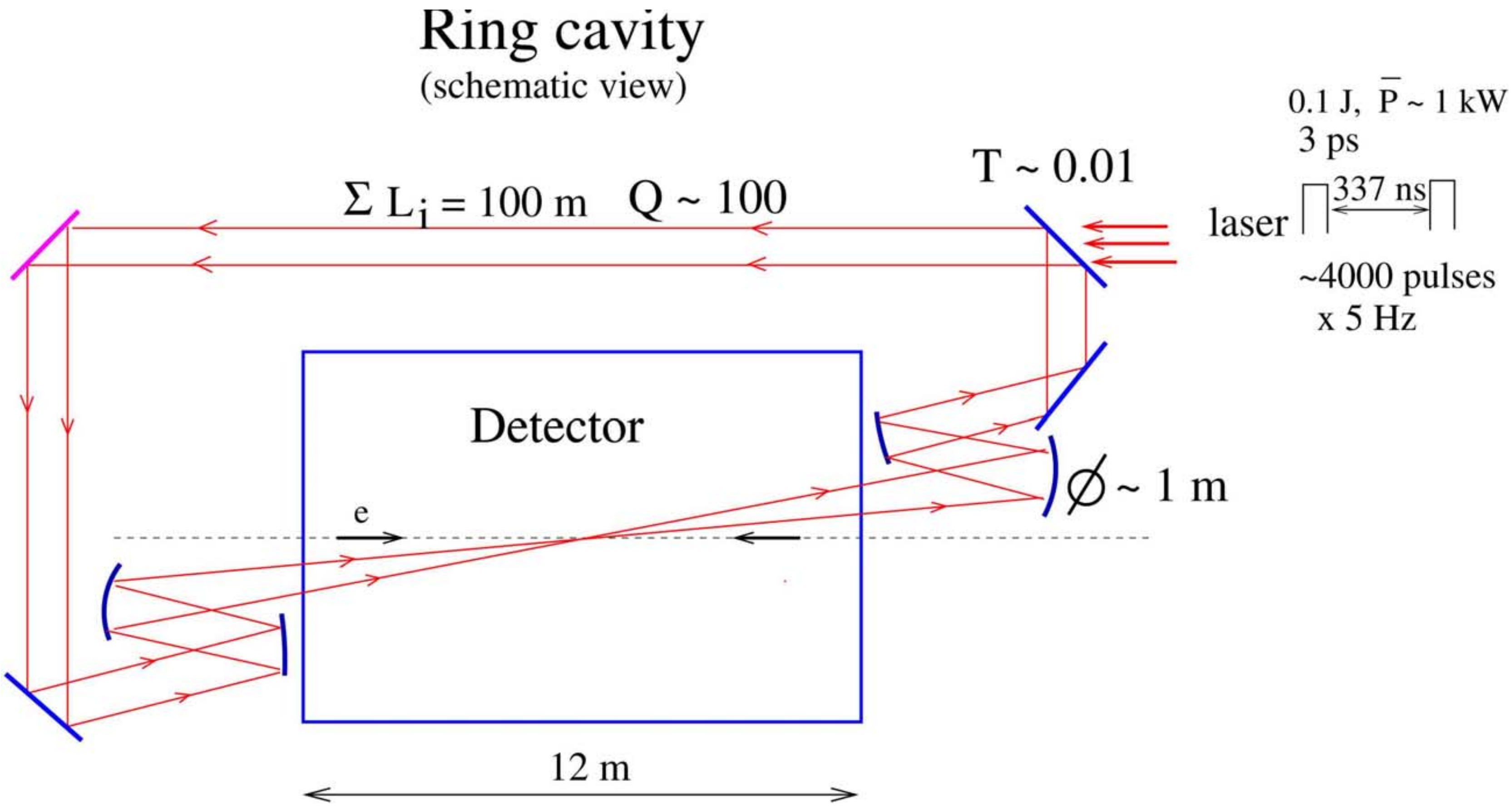
CLIC Δct~0.15 m, ~300 bunch/train, 50 Hz (f_{col}~15 kH)

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

CLIC –one pass system

(or short linear cavity?)

Laser system for ILC



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, $\sigma_{x,L} \sim 7$ μm

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.

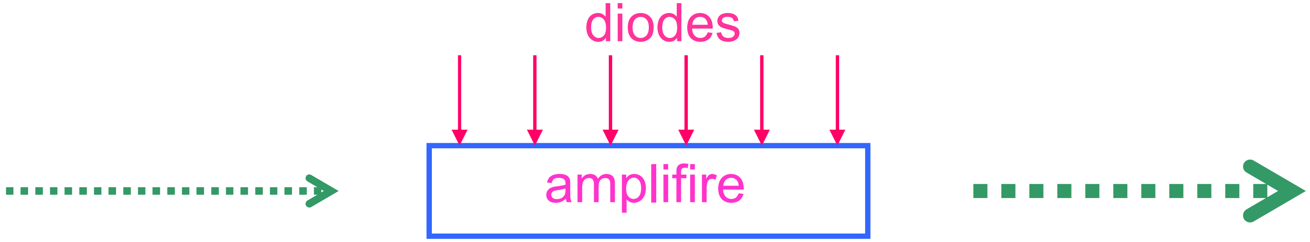
There were suggestions to use CLIC drive beams to generate light flashes (FEL), but they have not enough energy to produce the required flashes energy. In addition, the laser pulse should be several times shorter than the CLIC drive bunch.

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$.

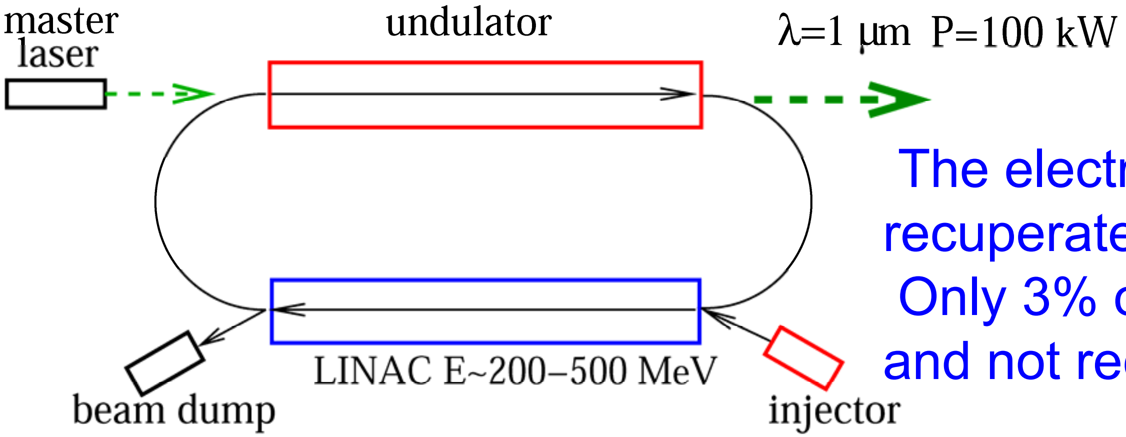
Experts say that such technology will be available only in one decade. LLNL works in this direction for laser fusion applications (λ~1μm).



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

Suggestion:

to use FELs instead of diodes for pumping of 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.

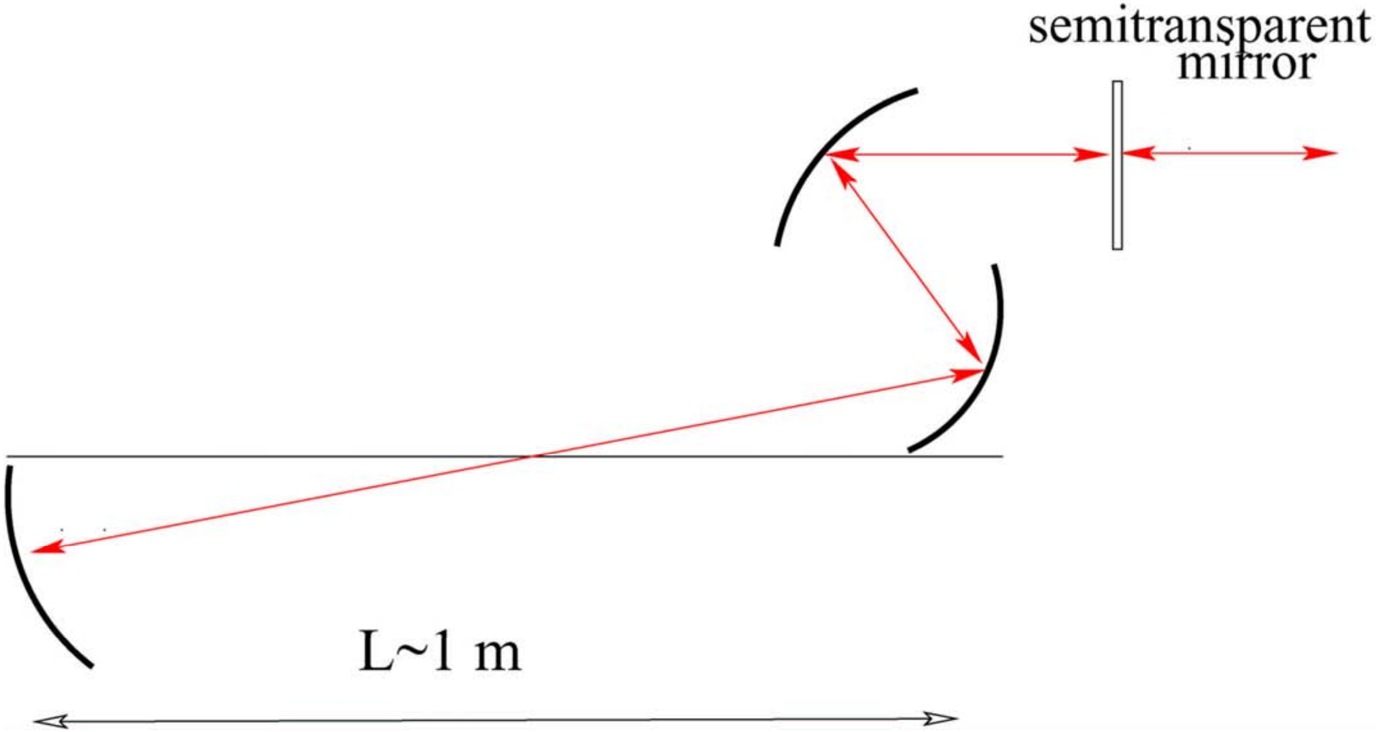
Storage of the pumping energy inside solid-state laser materials reduces the required FEL power inside the CLIC train by a factor 1 ms/ 177 ns=5600!

Such FEL can be built already now.

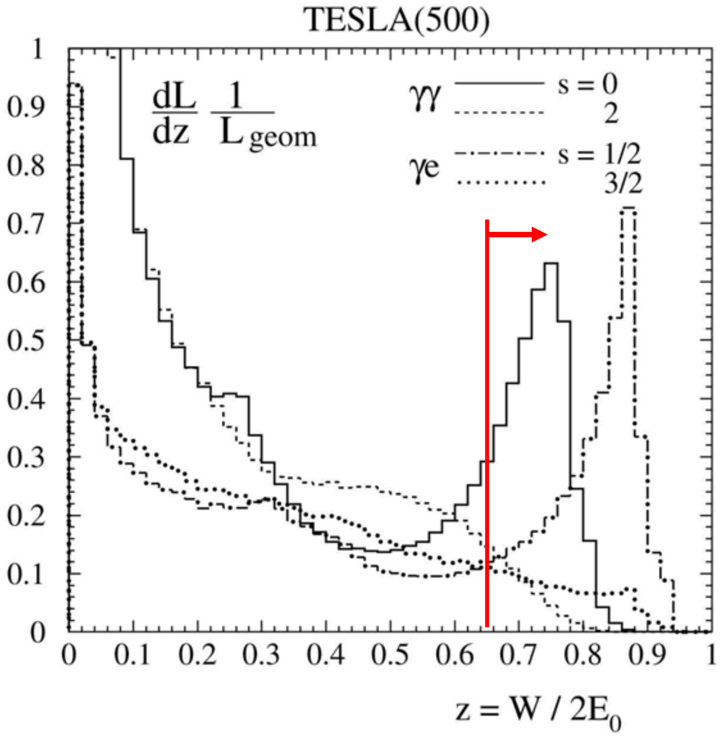
Another option: linear optical cavity

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.

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

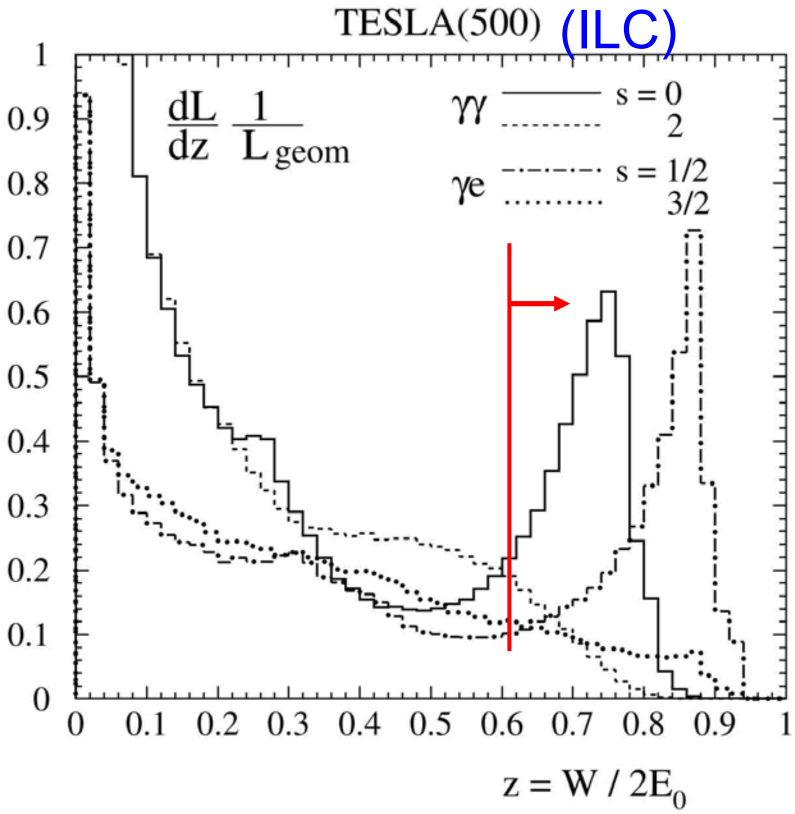
(this is not valid for multi-TeV colliders with short beams(CLIC) due to coherent e+e- creation)

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

It can be one order higher for beams with lower transverse emittances (there are ideas)

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 ILC beams (from DR)

$L_{\gamma\gamma}(z>0.8z_m) \sim 0.2 L_{e+e-}(\text{nom})$

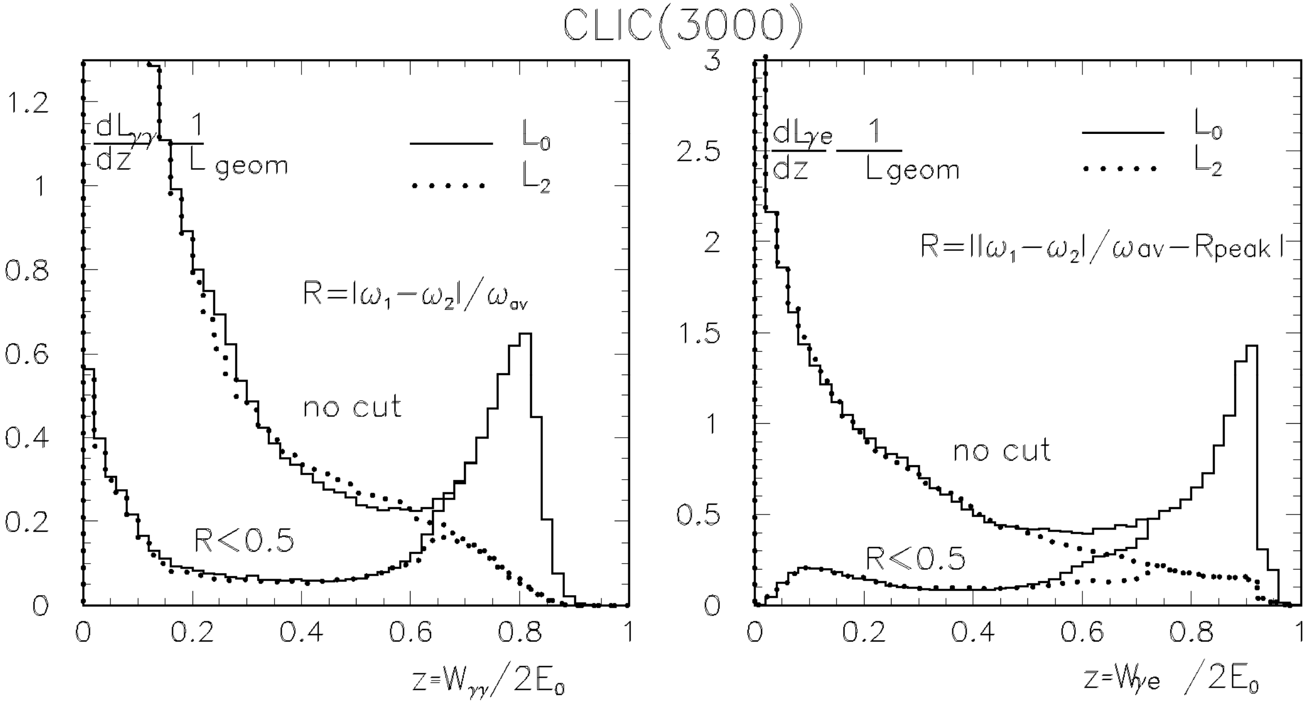
In the general case, at the ILC

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

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

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).

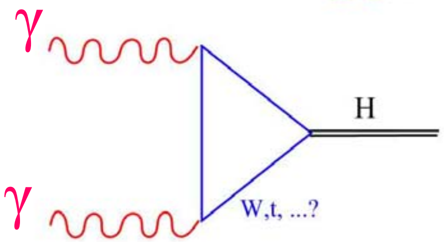
However, at CLIC the distance between bunches is very short and many events will overlap. A special detector with time stamps can help but not completely. At ILC the situation is much better.

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.

Several examples of physics at PLC

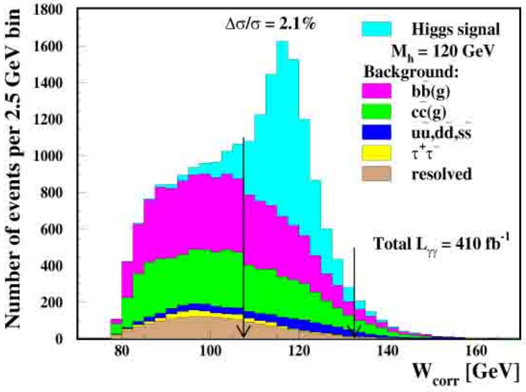
(just to remind)

Higgs boson

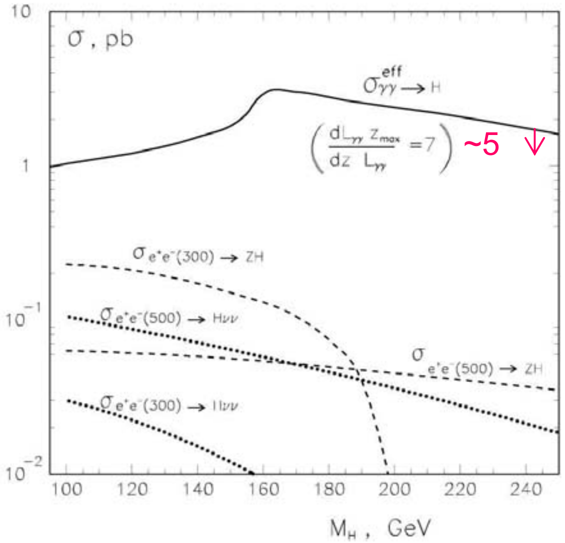


Very sensitive to heavy charge particles in the loop.

realistic simulation P.Niezurawski et al



Cross sections of the Higgs boson in $\gamma\gamma$ and e^+e^- collisions



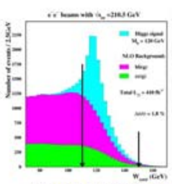
$$\dot N_{\gamma\gamma\to H} = L_{\gamma\gamma}\times\frac{dL_{\gamma\gamma}M_H}{dW_{\gamma\gamma}L_{\gamma\gamma}}\frac{4\pi^2\Gamma_{\gamma\gamma}(1+\lambda_1\lambda_2)}{M_H^3}$$

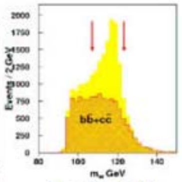
At ILC

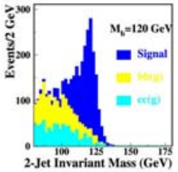
$$\frac{N(\gamma\gamma\to H)}{N(e^+e^-\to H+X)}\sim 1-10$$

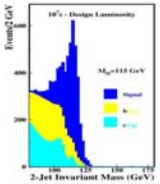
For M_H=115-250 GeV

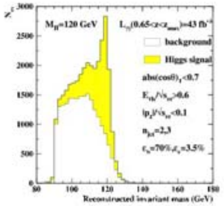
(previous analyses)


Niezurawski(TESLA)


Rosca(TESLA)


Asner(NLC)


Asner(Cliche)

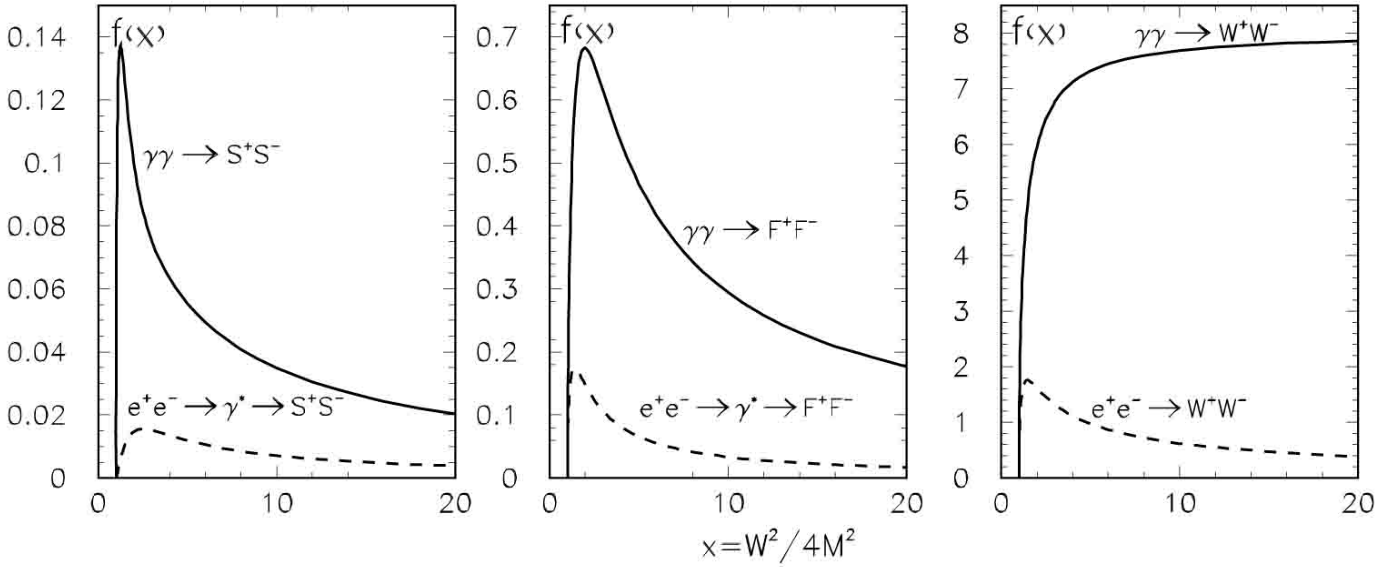

S.Soldner-Rembold

At nominal luminosities the number of Higgs in $\gamma\gamma$ will be similar to that in e+e-

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

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

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



unpolarized
beams

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

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:

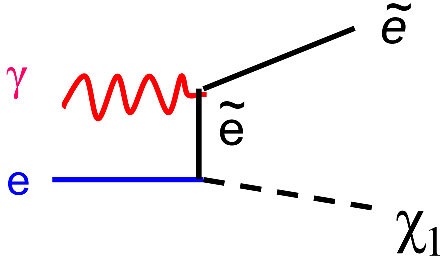
in e$^+$e$^-$ collisions $M_{H,A}^{max} \sim E_0$ (e$^+$e$^-$ $\rightarrow H + A$)
in $\gamma\gamma$ collisions $M_{H,A}^{max} \sim 1.6 E_0$ ($\gamma\gamma \rightarrow H(A)$)

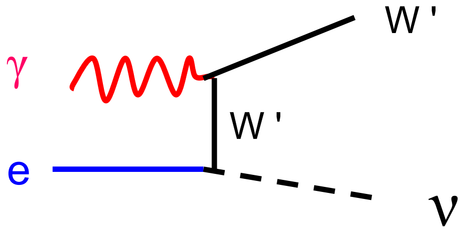
For some SUSY parameters H,A can be seen only in $\gamma\gamma$
(but not in e+e- and LHC)

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):

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





Gold-plated processes at photon colliders

Reaction	Remarks
$\gamma\gamma \to h_0 \to \bar{b}b$	$\mathcal{SM}$ (or $\mathcal{MSSM}$) Higgs, $M_{h_0} < 160\text{GeV}$
$\gamma\gamma \to h_0 \to WW(WW^*)$	$\mathcal{SM}$ Higgs, $140\text{GeV} < M_{h_0} < 190\text{GeV}$
$\gamma\gamma \to h_0 \to ZZ(ZZ^*)$	$\mathcal{SM}$ Higgs, $180\text{GeV} < M_{h_0} < 350\text{GeV}$
$\gamma\gamma \to h_0 \to \gamma\gamma$	$\mathcal{SM}$ Higgs, $M_{h_0} < 150\text{GeV}$
$\gamma\gamma \to H, A \to \bar{b}b$	$\mathcal{MSSM}$ heavy Higgs, for intermediate $\tan\beta$
$\gamma\gamma \to \tilde{f}\bar{\tilde{f}},\ \tilde{\chi}_i^+\tilde{\chi}_i^-,\ H^+H^-$	large cross sections, possible observ. of FCNC
$\gamma\gamma \to S[\tilde{t}\bar{\tilde{t}}]$	$\tilde{t}\bar{\tilde{t}}$ stoponium
$\gamma e \to \tilde{e}^-\tilde{\chi}_1^0$	$M_{\tilde{e}^-} < 0.9 \times 2E_0 - M_{\tilde{\chi}_1^0}$
$\gamma\gamma \to W^+W^-$	anomalous W interact., extra dimen.
$\gamma e^- \to W^-\nu_e$	anomalous W couplings
$\gamma\gamma \to WW + WW(ZZ)$	strong WW scatt., quartic anom. W, Z coupl.
$\gamma\gamma \to t\bar{t}$	anomalous top quark interactions
$\gamma e^- \to \bar{t}b\nu_e$	anomalous Wtb coupling
$\gamma\gamma \to$ hadrons	total $\gamma\gamma$ cross section
$\gamma e^- \to e^-X$ and $\nu_e X$	structure functions (pol. and unpol.)
$\gamma g \to \bar{q}q,\ \bar{c}c$	gluon distribution in the photon
$\gamma\gamma \to J/\psi\, J/\psi$	QCD Pomeron

Physics motivation: summary

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
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

Conclusions

- The main problem for PLC at CLIC is a short distance between bunches.

- Possible solution for one pass laser system with FEL pumping has been suggested.
  A linear optical cavity with Q~30 is also not excluded.