Prospects of high energy photon colliders

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Contents

- Introduction
- ILC
- CLIC
- SAPPHIRE, HFitt and others
- Super $\gamma\gamma$ factory
- Conclusion
Scheme of $\gamma\gamma$, $\gamma e$ collider

\[ \alpha_c \sim 25 \text{ mrad} \]

\[ \omega_c \sim 0.8 E_0 \]

\[ W_{\gamma\gamma, \text{max}} \sim 0.8 \cdot 2E_0 \]

\[ W_{\gamma e, \text{max}} \sim 0.9 \cdot 2E_0 \]

\[ \omega_m = \frac{x}{x + 1} E_0 \]

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

\[ E_0 = 250 \text{ GeV}, \ \omega_0 = 1.17 \text{ eV} \ (\lambda = 1.06 \mu\text{m}) \Rightarrow \]

\[ x = 4.5, \ \omega_m = 0.82E_0 = 205 \text{ GeV} \]

\[ x = 4.8 \text{ is the threshold for } \gamma\gamma_L \rightarrow e^+e^- \text{ at conv. reg.} \]

GKST 1981
The electron polarization increases the number of high energy photons nearly by factor of 2.

\[ \lambda_e \] – electron longitudinal polarization

\[ P_C \] – helicity of laser photons, \( x \approx \frac{4E_0^2\omega_0}{m^2c^4} \)
Ideal luminosity distributions, monohromatization

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

Electron polarization increases the \( \gamma\gamma \) luminosity in the high energy peak up to a factor of \( \sim 3 \) (at large \( x \)).
Highest energy scattered photons are polarized even at $\lambda_e=0$ (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 background
$$\sigma(\gamma\gamma \to b\bar{b}) \propto 1 - \lambda_1\lambda_2$$
Linear polarization of photons

\[ \sigma \propto 1 \pm l_1 l_2 \cos 2\varphi \pm \text{ for CP=±1} \]

Linear polarization allows to measure Higgs CP mixture and helps to separate SUSY H and A Higgs bosons
Realistic luminosity spectra ($\gamma\gamma$ and $\gamma e$)  
(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  
$L_{\gamma\gamma}(z>0.8z_m) \sim 0.1 \ L_{e-e-}(\text{geom})$  

(but cross sections in $\gamma\gamma$ are larger than in e+e- by one order!)

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$\gamma\gamma$ luminosity spectra with cuts on the longitudinal momentum

\[ \frac{dL_{\gamma\gamma}}{dz} \] for different cuts.

- No cut
- $R < 0.5$
- $R < 0.1$ (by jet collinearity)

\[ R = |\omega_1 - \omega_2| / \omega_{av} \]
Physics at PLC

Physics at PLC was discussed so many times (>1000 papers), it is difficult to add something essential. Most of examples were connected with production of the Higgs bosons or SUSY particles, e.t.c.

By now, only the light (standard) Higgs boson is discover.
Higgs decay branchings

SM predictions ($m_H = 125.5$ GeV):

- $\text{BR } (H \rightarrow WW) = 22.3\%$
- $\text{BR } (H \rightarrow ZZ) = 2.8\%$
- $\text{BR } (H \rightarrow \gamma\gamma) = 0.24\%$
- $\text{BR } (H \rightarrow b\bar{b}) = 56.9\%$
- $\text{BR } (H \rightarrow \tau\tau) = 6.2\%$
- $\text{BR } (H \rightarrow \mu\mu) = 0.022\%$

→ at 125 GeV: only ~11% of decays not observable (gg, cc)
Higgs to $\gamma\gamma$ at CMS

$\mu(\text{for } \gamma\gamma) \equiv \frac{\sigma}{\sigma_{SM}} = 0.77 \pm 0.27$
Higgs to $\gamma\gamma$ at ATLAS

Full dataset  ATLAS-CONF-2013-012

Selected diphoton sample

- Data 2011+2012
- Sig+Bkg Fit ($m_H = 126.8$ GeV)
- Bkg (4th order polynomial)

**ATLAS** Preliminary

$H \rightarrow \gamma\gamma$

$\sqrt{s} = 7$ TeV, $\int L dt = 4.8$ fb$^{-1}$

$\sqrt{s} = 8$ TeV, $\int L dt = 20.7$ fb$^{-1}$

Events / 2 GeV

Events - Fitted bkg

Mass:

$m_H = 126.8 \pm 0.2$ (stat) $\pm 0.7$ (syst) GeV

Signal strength:

$\mu := \sigma / \sigma_{SM} = 1.57 \pm 0.22$ (stat) $^{+0.24}_{-0.18}$ (syst)

(m$_H = 126.8$ GeV)
The resonance Higgs production is one of the gold-plated processes for PLC

This process is most sensitive to a new physics (high mass particles in the loop)

\[ \dot{N}_H = L_{ee} \times \frac{dL_{0, \gamma \gamma}}{dW_{\gamma \gamma} L_{ee}} \frac{4\pi^2 \Gamma_{\gamma \gamma}}{M_H^2} \left( 1 + \lambda_1 \lambda_2 + CP \ast l_1 l_2 \cos 2\varphi \right) = L_{ee} \sigma \]

\[ \sigma = \frac{0.98 \cdot 10^{-35}}{2E_0 [\text{GeV}]} \frac{dL_{0, \gamma \gamma}}{dz L_{ee}} \left( 1 + \lambda_1 \lambda_2 + CP \ast l_1 l_2 \cos 2\varphi \right), \text{ cm} \]

For realistic ILC conditions \( \sigma(\gamma \gamma \rightarrow H) \approx 75 \text{ fb} \) (in terms of \( L_{ee} \)),

while \( \sigma(e^+e^- \rightarrow HZ) \approx 290 \text{ fb} \)

in \( e^+e^- \quad \text{N}(H \rightarrow \gamma \gamma) \propto \sigma(e^+e^- \rightarrow HZ) \ast \text{Br}(H \rightarrow \gamma \gamma) L, \) where \( \text{Br}(H \rightarrow \gamma \gamma) = 0.0024 \)

in \( \gamma \gamma \quad \text{N}(H \rightarrow \gamma \gamma) \propto \sigma(\gamma \gamma \rightarrow H) \ast \text{Br}(H \rightarrow bb) L, \) where \( \text{Br}(H \rightarrow bb) = 0.57 \)

Conclusion: in \( \gamma \gamma \) collisions the \( \Gamma(H \rightarrow \gamma \gamma) \) width can be measured with statistics \((75 \ast 0.57)/(290 \ast 0.0024) \approx 60 \) times higher than in \( e^+e^- \) collisions.

This is one of most important argument for the photon collider (for Higgs study).
Remark on Photon collider Higgs factories

Photon collider can measure \( \Gamma(H \rightarrow \gamma\gamma) \times \text{Br}(H \rightarrow bb, ZZ, WW) \), \( \Gamma^2(H \rightarrow \gamma\gamma)/\Gamma_{\text{tot}} \), CP properties (using photon polarizations). In order to get \( \Gamma(H \rightarrow \gamma\gamma) \) one needs \( \text{Br}(H \rightarrow bb) \) from e+e- (accuracy about 1%). As result the accuracy of \( \Gamma(H \rightarrow \gamma\gamma) \) is about 1.5-2% after one years of operation. Can not measure cc, ττ, μμ due to large QED background.

e+e- can also measure \( \text{Br}(bb, cc, gg, \tau\tau, \mu\mu, \text{invisible}) \), \( \Gamma_{\text{tot}} \), less backgrounds due to tagging of Z.

Therefore PLC is nicely motivated in combination with e+e-: parallel work or second stage.
Measurement of the Higgs CP-properties

\[ \sigma \propto 1 \pm l_{\gamma_1} l_{\gamma_2} \cos 2\phi, \]

where \( l_{\gamma_i} \) are the degrees of linear polarization and \( \phi \) is the angle between \( \vec{l}_{\gamma_1} \) and \( \vec{l}_{\gamma_2} \), and the \( \pm \) signs correspond to CP\( = \pm 1 \) scalar particles.

Varying initial state photon polarizations one can measure the Higgs CP value with 5-10% accuracy after one year of operation.

(In e+e- collisons CP-violation can be measured only using particle correlations in final states)
Some examples of Physics (in addition to H(125))

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

Unpolarized beams ($S$ (scalars), $F$ (fermions), $W$ (W-bosons);
\[ \sigma = (\pi\alpha^2/M^2)f(x), \text{beams unpolarized} \])

Polarized beams

So, typical cross sections for charged pair production in $\gamma\gamma$ collisions is larger than in $e^+e^-$ by one order of magnitude (circular polarizations helps)
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 $M_{H,A}^{max} \sim 1.6E_0$ ($\gamma\gamma \rightarrow H(A)$)

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

At a $\gamma e$ 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):

$$m_{\tilde{e}^-} < 0.9 \times 2E_0 - m_{\tilde{\chi}_1^0}$$
Physics motivation for PLC
(independent on physics scenario)
(Shortly)

In $\gamma\gamma$, $\gamma e$ 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 $\gamma e$)
4. higher precision for some phenomena ($\Gamma_{\gamma\gamma}$, CP-proper.)
5. different type of reactions (different dependence on theoretical parameters)

It is an 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 (2001), etc.

The conversion region: optimization of conversion, laser scheme.

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. Recently LLNL started work on LIFE lasers for thermonuclear plant which seems very attractive (one pass laser). Further developments need political decisions and finances.
Crossing angle

At present it is important to make the ILC design compatible with the photon collider.
   Now for e+e- the crossing angle $\alpha_c = 14$ mrad
   For photon collider one needs $\alpha_c \approx 25$ mrad (because larger disruption angles)

   Dependence of $L_{\gamma\gamma}$ on $\alpha_c$:
   
<table>
<thead>
<tr>
<th>$\alpha_c$ (mrad)</th>
<th>$L_{\gamma\gamma}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 mrad</td>
<td>1</td>
</tr>
<tr>
<td>23 mrad</td>
<td>$\sim 0.76$</td>
</tr>
<tr>
<td>20 mrad</td>
<td>$\sim 0.43$</td>
</tr>
<tr>
<td>14 mrad</td>
<td>$\sim 0$</td>
</tr>
</tbody>
</table>

   CLIC needs 20 mrad.

   So, the ILC team should change $\alpha_c = 14$ to 23-25 mrad in order to have in future the possibility of CLIC and PLC in the same tunnel!
Requirements for laser

- Wavelength: ~1 μm (good for 2E<0.8 TeV)
- Time structure: Δct~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~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.
Laser system

Ring cavity
(schematic view)

The cavity includes adaptive mirrors and diagnostics. Optimum angular divergence of the laser beam is $\pm 30$ mrad, $\approx 9$ J (k=1), $\sigma_t \approx 1.3$ ps, $\sigma_{x,L} \approx 7$ $\mu$m.
Recently, new option has appeared, one pass diode pumped laser system, based on a new laser ignition thermonuclear facility: Project LIFE, LLNL. 16 Hz, 8.125 kJ/pulse, 130 kW aver. power. (the pulse can be split into the ILC train)

old (NIF)  new(LIFE), V=31 m³
Laser diodes cost go down at mass production, that makes one pass laser system for PLC at ILC and CLIC realistic!

Diode costs are the main capital cost in the system

- White paper co-authored by 14 key laser diode vendors
- 2009 Industry Consensus: $3/W @ 500 W/bar, with no new R&D

- Power scaling to 850 W/bar provides $0.0176/W (1st plant)
- Sustained production of LIFE plants reduces price to ~$0.007/W
- Diode costs for first plant: $880M
- Diode costs for sustained production: $350M

Laser for PLC cost ~ 3 M$

LIFElet (1st beamline) $0.1/W
diodes for 1 beamline $13M
Photon collider at CLIC
Laser system for CLIC

Requirements to a laser system for PLC at CLIC (500)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser wavelength</td>
<td>~ 1 μm (5 for 2E=3000 GeV)</td>
</tr>
<tr>
<td>Flash energy</td>
<td>A~5 J</td>
</tr>
<tr>
<td>Number of bunches in one train</td>
<td>354</td>
</tr>
<tr>
<td>Length of the train</td>
<td>177 ns=53 m</td>
</tr>
<tr>
<td>Distance between bunches</td>
<td>0.5 nc</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>50 Hz</td>
</tr>
</tbody>
</table>

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).
One pass laser system, developed for LIFE (LLNL) is well suited for CLIC photon collider

Project LIFE, LLNL 16 Hz, 8.125 kJ/pulse, 130 kW aver. power
(the pulse can be split into the CLIC train)
Photon collider Higgs factory
SAPPHiRE
SAPPHiRE: a Small $\gamma\gamma$ Higgs Factory

S. A. Bogacz\textsuperscript{1}, J. Ellis\textsuperscript{2,3}, L. Lusito\textsuperscript{4}, D. Schulte\textsuperscript{3}, T. Takahashi\textsuperscript{5}, M. Velasco\textsuperscript{4}, M. Zanetti\textsuperscript{6} and F. Zimmermann\textsuperscript{3}

Aug. 2012
The scheme is based on LHeC electron ring, but shorter bunches and somewhat higher energy, 80 GeV (extra arc).
Some critical remarks on SAPPHIRE

1. The emittance dilution in arcs.
2. Need low emittance polarized electron guns. Several labs are working on low emittance polarized RF guns, there is a good progress and results will appear soon.
3. The length of the ring 9 km (2.2 km linac, 70 km ! arcs). The “usual” warm LC with G=50 MeV/m would have L~4 km total length and can work with smaller emittances and thus can have a higher luminosity. Where is a profit?
4. The PLC with \( E = 80 \text{ GeV} \) and \( \lambda = 1.06/3 \text{ \(\mu\)m} \) \((x = 4.6)\) have very low energy final electrons, this courses very large disruption angles. Namely due to this reason for TESLA (ILC) we always considered the Higgs factory with \( E = 110 \text{ GeV} \) and \( \lambda = 1.06 \text{ \(\mu\)m} \) \((x = 2)\). In addition, at \( E = 110 \text{ GeV} \) the product of linear polarizations is 3 times larger \((9 \text{ times smaller running time for obtaining the same accuracy for CP parameter})\). The energies \( E > 100 \text{ GeV} \) are not possible at ring colliders like Sapphire due to unacceptable emittance dilution and the energy spread \((\text{the emittance increases is proportional to } E^6/R^4)\).

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).
Sapphire PC has stimulated many other proposals of ring gamma-gamma Higgs factories:
The total number of beamlines in the tunnel will be 16, with the total length of approximately 96 km. The eight arcs would be stacked one on top another, so electrons will jump up and down, by up to 1.5 m, 16 times per turn, 128 times in total. The vertical emittance will be completely destroyed on such “mountains”!
Laser for HFiTT

Fiber Lasers -- Significant breakthrough


ICAN – International Coherent Amplification Network

Figure 2: Principle of a coherent amplifier network (CAN) based on fiber laser technology. An initial pulse from a seed laser (1) is stretched (2), and split into many fibre channels (3). Each channel is amplified in several stages, with the final stages producing pulses of ~1 mJ at a high repetition rate (4). All the channels are combined coherently, compressed (5) and focused (6) to produce a pulse with an energy of >10 J at a repetition rate of 10 kHz (7). [3]

HFiTT needs 5 J at ~40kHz!

ICHEP-2014, July 5, 2014
arc magnets -17 passes!

beam 1
- 5.6 GeV
- 15.8
- 26.0
- 36.2
- 46.0
- 55.3
- 63.8
- 71.1
- 71.1
- 63.8
- 55.2
- 46.0
- 36.2
- 26.0
- 15.8
- 5.6

beam 2

HERA Tunnel Filler

laser or auto-driven FEL

\[ \rho=564 \text{ m} \] for arc dipoles
(probable pessimistic; value assumed in the following)

2x8+1 arcs

20-MV deflecting cavity (1.3 GHz)

3.6 GeV linac Gradient
\[ \sim 10 \text{ MV/m} \]

real-estate linac

5.6 GeV
15.8
26.0
36.2
46.0
55.3
63.8
71.1
71.1
63.8
55.2
46.0
36.2
26.0
15.8
5.6

3.6 GeV linac

2x1.5 GeV linac

20-MV deflecting cavity

0.5 GeV injector

F. Zimmermann, R. Assmann, E. Elsen,
DESY Beschleuniger-Ideenmarkt, 18 Sept. 2012

ICHEP-2014, July 5, 2014
Possible Configurations at JLAB

85 GeV Electron energy
γ c.o.m. 141 GeV
ICHEP-2014, July 5, 2014

103 GeV Electron energy
γ c.o.m. 170 GeV

Edward Nissen
Town Hall meeting Dec 19 2011
SLC-ILC-Style (SILC) Higgs Factor
(T. Raubenheimer)

• 2-pass design!

1.6 B$ without laser

Final focii ~ 300 meters in length
Laser beam from fiber laser or FEL
2 x 85 GeV is sufficient for $\gamma\gamma$ collider
Upgrade with plasma afterburners to reach 2 x 120 GeV for $e^+e^-$. Then final ring should have R=3.5 km (to preserve emittance).
KEK the X-band linear collider Higgs factory ($e^+e^-$, $\gamma\gamma$, $\gamma e$) with a total length 3.6 km only.

(R. Belusevic and T. Higo)

Why not? With $e^+e^-$.
“Higgs” Factory at the Greek-Turkish Border

Photon – Photon Collider Specific

ACCELERATOR
An electron linac with two arcs bending in opposite direction
Simple and cheap option

Two electron linacs facing each other, 80 GeV each
Option with better performance

Both options use the CLIC technology with gradient 100 MV/m, getting electron beam energy 80 GeV in ~1.5 km length (ILC SC technology 35 MV/m)

L~2 km!
(SLC type based on CLIC technology)
Plasma people also like photon colliders, because acceleration of electron is much easier than positrons.

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**TABLE II.** Example parameters for a 0.5 TeV laser-plasma linear $\gamma\gamma$ collider.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma number density, $n_0$ [cm$^{-3}$]</td>
<td>$10^{17}$</td>
</tr>
<tr>
<td>Beam energy, $\gamma mc^2$ [TeV]</td>
<td>0.25</td>
</tr>
<tr>
<td>Geometric luminosity, $\mathcal{L}$ [10$^{34}$ s$^{-1}$ cm$^{-2}$]</td>
<td>2</td>
</tr>
<tr>
<td>Number per bunch, $N$ [10$^9$]</td>
<td>4</td>
</tr>
<tr>
<td>Collision frequency, $f$ [kHz]</td>
<td>15</td>
</tr>
<tr>
<td>Number of stages (1 linac), $N_{\text{stages}}$</td>
<td>25</td>
</tr>
<tr>
<td>Linac length (1 beam), $L_{\text{total}}$ [km]</td>
<td>0.05</td>
</tr>
<tr>
<td>Total wall-plug power, $P_{\text{wall}}$ [MW]</td>
<td>80</td>
</tr>
<tr>
<td>Compton scattering laser wavelength [$\mu$m]</td>
<td>1</td>
</tr>
<tr>
<td>Compton scattering laser energy [J]</td>
<td>6</td>
</tr>
<tr>
<td>Compton scattering laser duration [ps]</td>
<td>7</td>
</tr>
<tr>
<td>Compton scattering laser Rayleigh range [mm]</td>
<td>1</td>
</tr>
<tr>
<td>Compton scattering intensity [10$^{18}$ W/cm$^{-2}$]</td>
<td>0.27</td>
</tr>
<tr>
<td>Gamma beam peak energy [TeV]</td>
<td>0.2</td>
</tr>
<tr>
<td>Conversion efficiency [$e \rightarrow \gamma$]</td>
<td>0.65</td>
</tr>
</tbody>
</table>

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My dreams of $\gamma \gamma$ factories

(PLC based on ILC, with very low emittances, without damping rings)
Factors limiting $\gamma\gamma, \gamma e$ luminosities

Collision effects:
• Coherent pair creation ($\gamma\gamma$)
• Beamstrahlung ($\gamma e$)
• Beam-beam repulsion ($\gamma e$)

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

At the ILC nominal parameters of electron beams $\sigma_x \sim 300$ nm is available at $2E_0=500$ GeV,
but PLC can work even with ten times smaller horizontal beam size.

So, one needs: $\varepsilon_{nx}, \varepsilon_{ny}$ as small as possible and $\beta_x, \beta_y \sim \sigma_z$
Production of beams with low transverse emittances: (Method is based on beam combining in the longitudinal phase space) 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, $E_{\text{min}} \sim 75$ 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 $\varepsilon_{nz} \sim 2 \cdot 10^{-3}$ 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.
Scheme of combining one bunch from the bunch train (for ILC)

(64→1)

**Hopes**

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

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

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

The ratio of geometric luminosities

$$L_{RF\text{gun}}/L_{DR}=\sim 10$$

So, with polarized RF-guns one can get the luminosity $\sim 10$ times higher than with DR.
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, it is important to change of the crossing angle from 14 to ~23-25 mrad to make ILC compatible with PLC. Due to the LIFE project one pass laser scheme becomes very attractive (easier than the optical cavity).

• PLC at CLIC is more difficult due to much shorter trains. However LIFE help here as well.

• Ring photon colliders, like SAPHIRE and HFiTT does not look realistic due to technical problems, restriction on energy and absence of e+e- collisions. Photon colliders for Higgs study without e+e- have not sufficient physics case.

• PLC without damping rings seems possible, could have even higher (or much higher) luminosity, needs further study. That could open the way to yy factories, to precision measurement of the Higgs self coupling, etc (if there is any new physics in the sub-TeV region).