# Photon collider before e$^+$e$^-$, has it sense?

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# History of the question

The photon collider ($\gamma\gamma,\gamma e$) is usually considered as a natural supplement to $e^+e^-$, $e^-e^-$ linear collider which allows to study new physics in different types of collisions at the cost of rather small additional investments.

Usually we assumed that LC starts with $e^+e^-$ and comes to $\gamma\gamma,\gamma e$ several years later, even in the case of two IP.

However, already many times people suggested to build the photon collider before e+e-(or even without e+e-), just because it is simpler (no e+, may be no damping rings) and somewhat lower beam energy is needed to produce the intermediate mass Higgs boson.

Several such suggestions (not all):

V.Balakin, I. Ginzburg, LCWS93; V.Balakin, A.Seryi, GG-col, LBL,1994 (2x100,VLEPP based)

D.Asner et al, 2001, CLICHE (based on CLIC 1 with $E_b$=70 GeV)
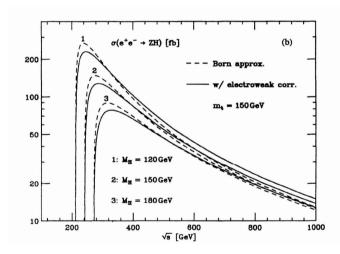
H.Sugawara, Photon-photon collider Higgs factory as a precursor to ILC, ILCSC, 2008.

# Beam energies for the Higgs production

Indeed, the maximum energy of photons is $\quad E_\gamma = \dfrac{x}{x+1} E_0 \qquad x = \dfrac{4 E_0 \omega_0}{m^2 c^4}$

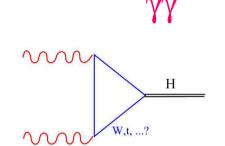$E_\gamma \sim 0.8\, E_0$ (at $x \leq 4.8$).

In $\gamma\gamma$ collisions in order to produce single h(120) one needs $2E_0 = 120/0.8 = 150$ GeV $+10\%$(for scanning)$= 165$ GeV.

In $e^+e^- \to Z\, h$, one needs $2E_0 \sim 235$ GeV, or higher by a factor of 1.4.
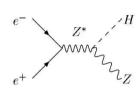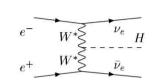
# Properties of the photon collider for the Higgs study:
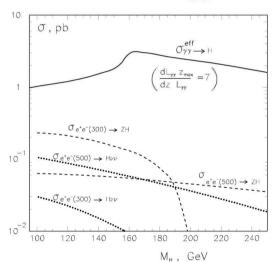# Luminosity

γγ

e⁺e⁻

Very sensitive to heavy charge

particles in the loop.

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

$\left(\dfrac{dL_{\gamma\gamma}}{dz}\dfrac{Z_{max}}{L_{\gamma\gamma}}=7\right)$

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

At TESLA

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

for $M_H = 100 - 250$ GeV.

The effective cross section γγ→h(120) (with account of the energy spread)
is about 1 pb, while that of e⁺e⁻→Z h is 0.2 pb (see previous slide)
For the same beams $L_{\gamma\gamma}$~$0.2L_{e+e-}$,  so the number of events will be similar.
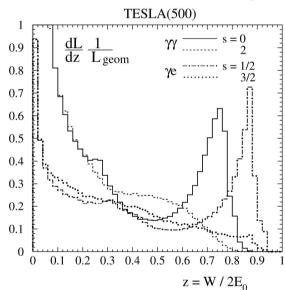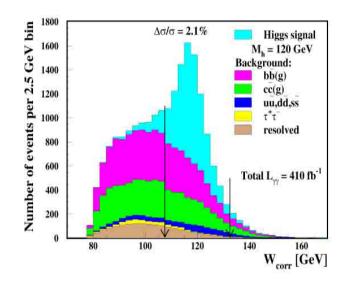
# Properties of the photon collider for the Higgs study:
# Polarization

Higgs is produced by two photons in helicity state 0.
Main background, QED process $\gamma\gamma \to cc$, bb, is produced by photons with helicity 2.

Luminosity spectra for 85% polarized electrons
and 100% laser photons

At the high energy edge $L_0/L_2 \sim 10$



The high photon polarization is crucial
for suppression backgrounds.

If laser photons are polarized but electrons are unpolarized then $L_0/L_2 \sim 1.5$ and
the Higgs boson will be invisible. In addition the absence of electron polarization
leads to the decrease of the luminosity in the peak by a factor of 3.

Presence of a high electron polarization is obligatory!

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# Damping rings

Existing DC photo-guns produce highly polarized electron beams but with large normalize emittances. Without cooling in damping rings the luminosity will be smaller by a factor of 100!
RF polarized sources with small emittances do no exist.

So, the damping ring is mandatory for the photon collider for the Higgs study!

The only element which absence in the photon collider is the positron source, but in addition it has the laser system.

Resume: technically the photon collider for h(120) is not easier and may be somewhat cheaper only due to lower energy.

# Higgs study in e⁺e⁻ and $\gamma\gamma$ collisions

The goal is not just the Higgs production but investigation of its properties, coupling to different particles.

   The channel e⁺e⁻ →Zh is very unique, detecting Z→$\mu\mu$ one can reconstruct the recoil mass and thus to "see" even invisible Higgs decays. This channel allows to measure different branching (h→bb,cc,$\tau\tau$,gg,WW, $\gamma\gamma$) and the Higgs spin, namely this is required for demonstration that this particles is the Higgs boson.

   The photon collider (at this Higgs mass) can measure only $\Gamma_{\gamma\gamma}$(h)·Br(h→bb) and  $\Gamma_{\gamma\gamma}$(h)·Br(h→$\gamma\gamma$). The value $\Gamma_{\gamma\gamma}$(h)·is very important quantity, it can be measured at the photon collider with much better accuracy but for this one needs to know Br(h→bb), which can be measured only at e⁺e⁻. Other channels, h(120)→cc,$\tau\tau$,gg,WW, can not be extracted at the photon collider due to large SM backgrounds.

So, the minimum e⁺e⁻ collider will be somewhat more expensive than the PLC but much more powerful for study of the Higgs boson.

# If e⁺e⁻ is much better for the Higgs study, why we need the photon collider at all?

The reasons are the following (independent of physics scenarios):

1. It is the unique case when the same collider can study new physics in several types of collisions at the cost of rather small additional investments
2. In $\gamma\gamma$, $\gamma e$ collisions compared to e⁺e⁻ the energy is smaller only by 10-20%;
3. The number of events is similar or even higher;
4. Access to higher particle masses (H,A in $\gamma\gamma$, charged and light neutral SUSY in $\gamma e$);
5. Higher precision for some phenomena;
6. Different type of reactions (different dependence on theoretical parameters);

   One example: detection of the heavy SUSY Higgs boson. Let $2E_0$=500 GeV.

   in e+e-  $M_{H,A}$(max)~250 GeV (H,A are produced in pairs);

   in $\gamma\gamma$ $M_{H,A}$(max)~400 GeV (a single resonance).

We don't know what physics expects us in a new energy region (LHC will see not all). The photon collider can add new information and even can observe physics and particles not accessible for e⁺e⁻ (at fixed energy).

   But, if we want to built a low energy linear collider for study of the "standard) h(120) we certainly need e⁺e⁻ for justification of the multi-B$ facility,

the minimum LC energy is determined by the reaction e⁺e⁻→Z h !

# The cost problem

The ILC(500) is too expensive (for politicians). What to do?
One can reduce the energy for the first stage, 2E=235 GeV, for example.
But the ILC(500) linac contributes 60% to the total cost, so the decrease
of the energy down to 235 GeV reduces the cost only by 30%.

   More radical is a change of a ILC technology. The warm linac will be
certainly cheaper and the DR will be smaller due to shorter trains.

   What are possibilities:
S-band (klystrons), as SLAC (also SBLC, DESY project)
C-band (KEK)
X-band (NLC,JLC)
X-band (CLIC, two beams)

   Many year ago G.Voss tried to convince the LC community that the
S-band technology is practically optimum for the LC cost. Beside this
technology is well developed. Why not?

   It seems we should seriously revisit the LC technology choice.

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# Which (warm) LC technology is most preferable for the photon collider?

Main difference (for the photon collider) between these technologies is the difference in the pulse structures.

|  | N | $\sigma_z$,mm | $\Delta t$,ns | $n_b$ | $\Delta t_{,tr}$,$\mu$s | $\nu$, Hz |
|---|---|---|---|---|---|---|
| S-band SBLC | 1.1 | 0.3 | 6 | 333 | 2 | 50 |
| x-band NLC/JLC | 0.75 | 0.11 | 1.4 | 192 | 0.27 | 120 |

1. Laser power, possibility of the optical cavity.

   S-band is certainly better, allows the optical cavity with 2/0.27=7 time higher Q-factor than for X-band. In comparison with SC ILC, the laser system for the S-band may be even easier: needs smaller instantaneous power of diodes to pump the train (namely this determined the diode cost). For ILC one need create effectively 3000/Q~20  10 J laser bunches during 1 msec. (Note, the pumping time of the laser medium is also about 1 msec, $\geq$ any of considered train durations). For SBLC the corresponding number is the number of bunches which circulate in the cavity. If the cavity is linear with 2L=12 m (40 ns), n=40/6~7. For the ring cavity with C=50 m n=28. In addition Q factor needed for SBLC is considerably smaller than for SC ILC therefore it is easier to stabilize the cavity.

   Resume:  Laser system for S-band is easier than for X-band and (may be) even easier than  for SC ILC.

## 2. Multibunch instability.

This phenomenon is known for e⁺e⁻, namely due to this effects colliders with small distance between bunches need large crossing angle in order to reduce influence of the outgoing (from IP) bunches to the bunch traveling to the IP. At photon colliders this effect is much stronger due to strong repulsion of beams at the IP and lower energies (after Compton conversion).

Calculations show that at E=80 GeV at x-band (NLC) the vertical displacement of the beam coming to the IP is several times larger than the vertical beam size. Stabilization of collisions is a problem!

For S-band this effect is smaller. Moreover the first parasitic collisions takes place at the distance 90 cm from the IP where the horizontal distance between bunches is 90*0.025=2.25 cm. It seems possible to put a local screen between bunches and completely suppress this effect.
Resume: S-band is much better.

## 3.Overlap of events.
For experimentation larger time between bunches, i.e.S-band, is preferable.

Three considered problems are most important, in other aspects the differences between varions LC-types are less dramatic.

# Conclusion

- Though I love the photon collider and advocate its construction but, in my opinion, the first photon collider should be constructed as a supplement for e+e-. Such sequence has much better motivation for the Higgs study.

- In order to make the LC cost acceptable for politicians it worth to start from lower energy, say $2E=\sim1.1(M_h + M_Z)$, if the Higgs exists, with possibility of upgrade up to tt quark threshold 2E=350 GeV.

- It worth to revisit the warm, possible S-band, technology which allows more essential cost reduction.

- For the photon collider S-band technology is attractive than X-band.