COMPARISON of WARM and COLD PHOTON COLLIDERS

V.I. TELNOV
Institute of Nuclear Physics, 630090, Novosibirsk, Russia

Photon collider based on cold and warm linear collider technologies are compared from the point of view of attainable luminosities, technical feasibility of laser systems and experimental conditions.

1 Introduction

On August 20, 2004, ten day before the deadline for this Proceedings, the International Committee for Future Accelerators following the recommendation of International Technology Recommendation Panel announced that International Linear Collider (ILC) is to be realized in superconducting technology. So, all discussions are finished. Nevertheless, even now it has sense to summarize what is acquired and what is lost due to such decision. I would like also to express my personal opinion about only one linear collider (LC) in the world.

1.1 One or two colliders?

All history of the mankind has proved that a monopoly in any field is bad, in economics monopolies are forbidden by law, why it should be good in science? Competition in science is not less important than in economics. There are many examples. In the case of linear colliders it was not necessary to create artificially competing LC projects, they existed and were developed for 15–20 years by very strong regional collaborations and had similar readiness for the construction.

It would be wise to launch simultaneously the construction of two linear colliders, the superconducting, cold “TESLA-like” on the energy $0.5 \rightarrow 0.8$ TeV and the warm “NLC/GLC-like” on the energy $0.5 \rightarrow 1.5$ TeV, then five year later the CLIC on the maximum energy $3\rightarrow 5$ TeV. At start first two collider would have similar energy and study new physics together, after that TESLA investigates more carefully in the sub-TeV region while NLC/GLC goes to 1.5–2 times higher energies. Beside the “monopoly” reasons, the energy region from 0.1 to 1.5 TeV is too large for one collider, also it takes long running time for investigation of all interesting energy points and types of collisions.

This point of view I expressed at LCWS02 in Korea and privately many people told that they have similar opinion. I believe that the “competition” argument is very important, if possible, “global” projects should be avoided.
1.2 The case of the Photon Collider

The photon collider is based on the $e^+e^-$ collider. High energy photons are produced by Compton scattering of laser photons on high energy electrons. The expected number of interesting events is even higher than in $e^+e^-$ collisions. In $\gamma\gamma, \gamma e$ collisions one can study the same particles as in $e^+e^-$ collisions but in different reactions which is very important for understanding new phenomena. An additional cost is mainly the cost of the laser system which is about 2-3% of the total LC cost (the second interaction region with the detector is planned in any case). So, the case is obvious, paying small incremental cost we can get new types of collision with a great physics potential.

2 Comparison of cold and warm photon colliders

Below we compare two photon colliders: cold superconducting TESLA-like collider and warm NLC/GLC-like colliders.

2.1 Luminosities

At sub-TeV photon colliders beam collision effects are not important and $\gamma\gamma$ luminosities are just proportional to the geometric luminosity $L_{geom} = N^2\nu/(4\pi\sigma_x\sigma_y) \propto N^2\nu/\sqrt{\beta_x\beta_y\epsilon_{nx, ny}}$. In TESLA the beam power $P \propto N\nu$ is 1.65 times larger than in NLC/GLC due to 2.5 times better efficiency of the energy transfer from the wall plug to the beam. Moreover, TESLA can accelerate beam with larger number of particles, which is advantageous for the photon collider ($L \propto P \cdot N$). The minimum value of the vertical $\beta$-function $\beta_y \sim \sigma_z$. The minimum value of the horizontal $\beta$-function is determined by the chromo-geometric aberrations of the final focus system, for TESLA it is about 1.5 mm, for NLC/GLC it is also quite similar. Below we assume that they are equal.

Normalized emittances of electron beams produced in damping rings are determined by synchrotron radiation, intra-beam scattering and a tune shift due to the beam space charge. In the TESLA case the train is much longer, therefore the circumference $C_{DR}$ should be larger, in TESLA TDR it is 17 km. This causes the problem of the tune shift which is proportional to $C_{DR}N/\sqrt{\epsilon_{nx, ny}}$. At present conference S.Mishra told us about a new approach to the damping ring for TESLA with three times smaller circumference and by a factor of four smaller the horizontal emittance compared to those in the TESLA TDR for $e^+e^-$ collisions (for $\gamma\gamma$ collisions in the TESLA TDR we assumed four times better $\epsilon_{nx}$, but it was somewhat risky number). As the result, the normalized transverse emittances produced by the TESLA and NLC/GLC damping rings are almost equal. During the extraction and acceleration the emittances are
diluted somewhat, smaller in the cold case due to smaller wake fields. The beams parameters at the interaction point are presented in Table 1. The ratio of geometric luminosities $L_{\text{TESLA}}/L_{\text{NLC/GLC}} \approx 3$ in favour of the TESLA.

| Beam parameters of the cold and warm colliders |
|-----------------------------------------------|
| $N$ | $10^{10}$ | $\nu$ | kHz | $\sigma_z$ | mm | $\beta_x/\beta_y$ | mm | $\epsilon_{nx}/\epsilon_{ny}$ | $10^{-6}$ m |
| TESLA | 2 | 14.1 | 0.3 | 1.5/0.3 | 3/0.03 |
| NLC/GLC | 0.75 | 23 | 0.11 | 1.5/0.11 | 3.5/0.035 |

2.2 Laser systems

The main difference of laser systems for TESLA and NLC/GLC is connected with the time structures of electron trains. In the TESLA: rep. rate 5 Hz, the number of bunches in the train 2820 with the interval 337 nsec, the train duration is 1 msec; in NLC/GLC the corresponding parameters are: 120 Hz, 192 bunches, 1.4 nsec (we assume the same structure as for $e^+e^-$) and 270 nsec. The train duration in the TESLA is longer than the storage time of laser media (about 0.5-1 msec). The instantaneous laser power during the train is about $5J \times 2820/0.001 \sim 14$ MW for one beam, which is prohibitively large, if each laser bunch is used only once. For NLC/GLC one can use advantage of the medium storage time, then the effective average power is about $1.5J \times 192/0.0005 \sim 0.6$ MW, which is acceptable. On the other hand, the large distance between electron bunches in TESLA allows to use an external optical cavity which can reduce the input laser power by a factor of 100, this make the laser system much cheaper and more efficient than for the NLC/GLC. Note, that though the external optical cavities exist in many laboratories, but not for so short (1 psec) and powerful pulses, while for NLC/GLC the laser system can be based on the single pass lasers developed for fusion.

2.3 Experimentation

The average number of background $\gamma\gamma \rightarrow \text{hadron}$ events at photon colliders is about 1–2 per bunch crossing. At TESLA each bunch collision is seen by the detector separately. In NLC/GLC the train is very short and the calorimeter will integrate a whole train. However, in Si-W calorimeter, a very good timing resolution is possible. The whole train is recoded but then the time for each energy cluster can be determined with several nsec resolution. However, in any case, the background situation at TESLA will be better.
2.4 The beam dump

High energy photon beam at the photon colliders are very narrow, powerful and can not be deflected by magnets. This can cause overheating and material stress problems. The situation is more severe for TESLA because the number of particles in one train is 40 times larger than at NLC/GLC while the train duration is still smaller than the thermal diffusion time. On the other hand, for the thermal stress the characteristic times is 
\[ t_s \sim \frac{d_{\text{heat}}}{v_{\text{sound}}} \sim 1 \text{ mm/5 km/sec} \sim 2 \cdot 10^{-7} \text{ sec} \]
which integrates the whole train in NLC/GLC and only one bunch in TESLA. A possible solution for TESLA beam dump is considered in other my talk at this conferences. It is important technical problem, but, if solved, it does not influence photon collider parameters.

3 Conclusion

The $\gamma\gamma$ luminosity at the cold LC can be higher by a factor of three for present designs. The laser system is cheaper and more elegant for the cold LC (the optical cavity), but one pass laser system for the warm LC is more developed. The problem of the hadronic background is much easier for the cold LC, but probably it can be solved for the warm LC as well. It is good that ICFA has decided to push forward the cold linear collider. However the era of warm linear colliders is not finished, the CLIC project is the only feasible candidate for the multi-TeV region.

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