Comparison of cold and warm photon colliders

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Introduction

Main differences between warm and cold LCs:

- Luminosity. C-LC has lower RF frequency, higher RF-to-beam power efficiency, can accelerate bunches with larger N and larger σ_z, smaller wakefields, therefore smaller emittance delution – all these features are nice for obtaining larger luminosity. However, the $\gamma\gamma$ luminosity is proportional to the geometric e^-e^- luminosity, obtaining of small emittances are more difficult for c-LC due to larger circumference of the damping ring (the space charge turn shift). So, the resulting gain in the luminosity for c-LC may be not too large.

- Lasers. Due to very different bunch train structure at c-LC and w-LC laser systems should be very different. C-LC due to a large distance between bunches can use an optical cavity which considerably reduces the laser power. On the other hand, w-LC is easier for one pass laser scheme (due to smaller number of bunches in the train and possibility of energy storage in the laser medium).

- Backgrounds The average number of $\gamma\gamma \rightarrow hadron$ events at photon collider is about one per bunch crossing. C-LC has a large distance between bunches (337 ns) and there are no overlaps of events from different bunches. Calorimeters of w-LC will intergrate signals from many bunches ($\Delta_t = 1.4$ ns), therefore the hadronic background at w-LC is more severe.

- Beam dump. The number of bunches in c-LC train is larger, therefore the energy deposition during one train is also larger (the train duration is shorter in both cases than the characteristic time for the heat removal). On the other hand, the mechanical stress is smaller for c-LC (stress relaxation time is determined by the speed of the sound). Note, that the beam dump for photons is more difficult than for electrons because the photon beam is very narrow and can not be swept by the deflecting system.

Assumptions in the present consideration

Collisions effects at photon collider are not essential for energies below 1 TeV and therefore one can dream about ultimate luminosities using novel methods of low emittance beam production (such as laser cooling of electron beams). However, in the present consideration, we assume that the design of the LC is driven mainly by e^+e^- program and additional requirements from the photon collider side should be small, realistic and rather conservative.

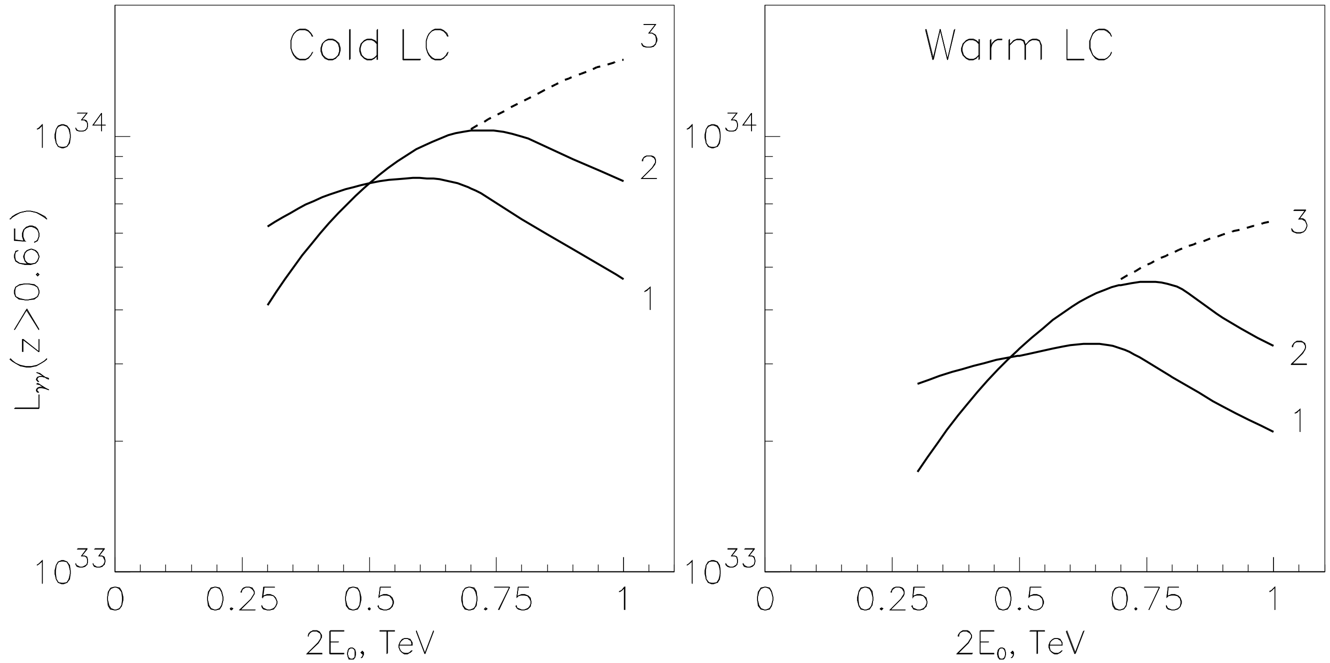
Luminosity

In the first approximation the $\gamma\gamma$ luminosity is proportional to the geometric e$^+$e$^-$ luminosity.

For NLC at Snowmass (2001) $N = 0.75 \times 10^{10}, \sigma_z = 0.11$ mm, $n_b \times \nu = 22800$, $\epsilon_{nx}/\epsilon_{ny} = 360/3.5{\times}10^{-8}$ m rad. For TESLA TDR (2001) $N = 2.0{\times}10^{10}, \sigma_z = 0.3$ mm, $n_b \times \nu = 14100$, $\epsilon_{nx}/\epsilon_{ny} = 300/3 \times 10^{-8}$ m rad (ϵ_{nx} specially decreased for the photon collider). If we take $\beta_y = \sigma_z$ and $\beta_x \sim 1.5$ mm (limitted by chromo-geometric abberations, the number is not well known) then $L_{TESLA}/L_{NLC} = 3.15$.

Parameters of US cold-warm study (2004) are somewhat more conservative, especially for c-LC. All are the same, but emittances are somewhat changed: For w-LC: $\epsilon_{nx}/\epsilon_{ny} = 360/4$ and for c-LC $\epsilon_{nx}/\epsilon_{ny} = 960/4$ for e$^+$e$^-$ mode. However, in c-LC damping ring $\epsilon_{nx}/\epsilon_{ny} = 800/1.4$, the product is determined by space charge turn shift. In order to decrease the delution of the emittances product during the transportation and acceleration it is reasonable to redistribute the emittances: $\epsilon_{nx}/\epsilon_{ny} = 300/3.7$ in the damping ring, then $\epsilon_{nx}/\epsilon_{ny} = 360/5$ (roughly) at the IP. This increase the luminosity by a factor of 1.45. In this case $L_{TESLA}/L_{NLC} = 2.4$ (1.65 without readjustment of the damping ring).

Dependences of $\gamma\gamma$ luminosities on the energy



1 – k=0.64 at 2E=500, flash energy = const, χ^2=const, λ=1.05 μm
2 – k=0.64 at all energies, $\chi^2 \propto A$, λ=1.05 μm
3 – k=0.64 at all energies, $\chi^2 \propto A$, λ=1.47 μm (to avoid pair creation)

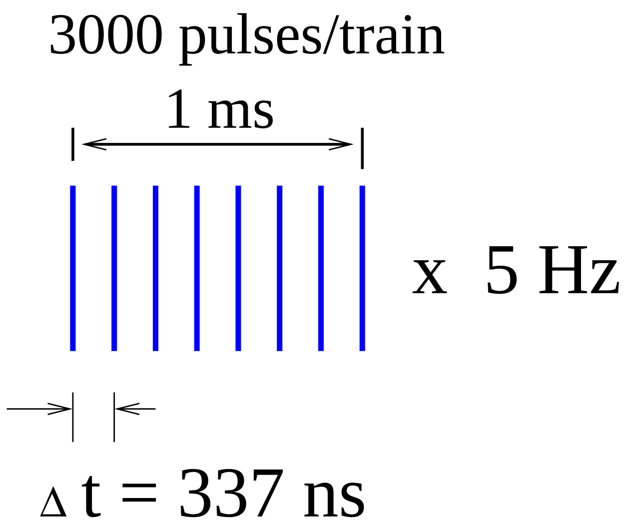
If the laser wave length is fixed, the Compton cross section decreases with increasing the energy, consequently the conversion coefficient decreases. Moreover, for $x > 4.8$, the e^+e^- pair creation in the conversion region is possible which leads to large decrease of the conversion coefficient at large x. Laser with $\lambda \sim 1.05$ μm (most developed powerful lasers) can be used up to the energy of about $2E_0 = 750 - 800$ GeV. For $2E_0 = 1$ TeV it is desirable to use lasers with $\lambda \sim 1.5$ μm.

Laser and optics.

Requirements to the Laser for TESLA

Flash energy	≈ 5 J
Duration	$\tau(rms) \approx 1.5$ ps
Repetition rate	TESLA collision rate, ≈ 14 kHz
Average power	≈ 140 kW (for one pass collision)
Wavelength	≈ 1 μm(for all TESLA energies).

Structure of electron beams at TESLA

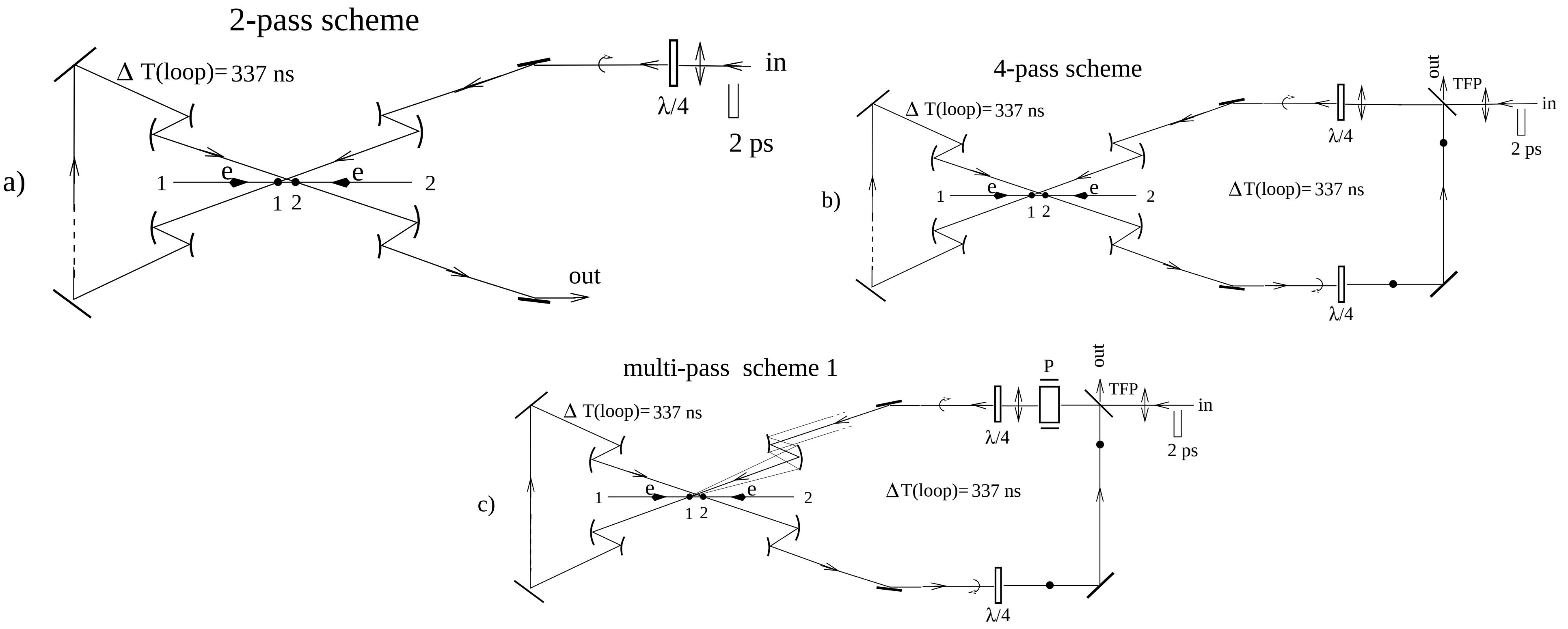


Too large average power. Multiple use of the same laser pulse is desirable.

Two possible laser schemes are considered:

- optical trap;
- external optical cavity.

The Optical Trap.

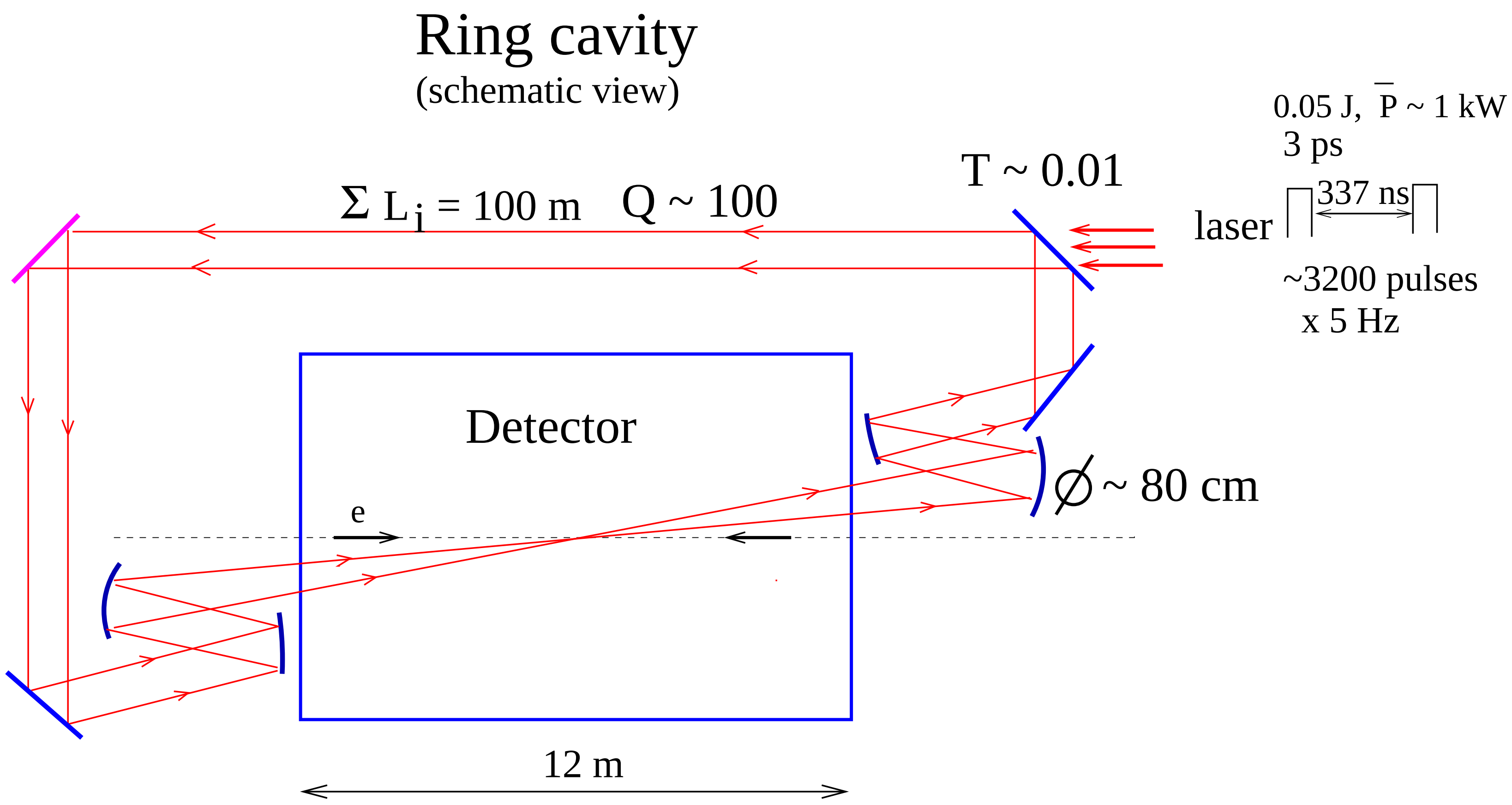


The scheme c) is the best, allows about 6 round trips (12 collisions with electron bunches) for $R \sim 99.8\%$(99.95% is possible).

Nonlinear effects in optical elements is the main problem, but can be solved using adaptive optics and spacial filters.(?)

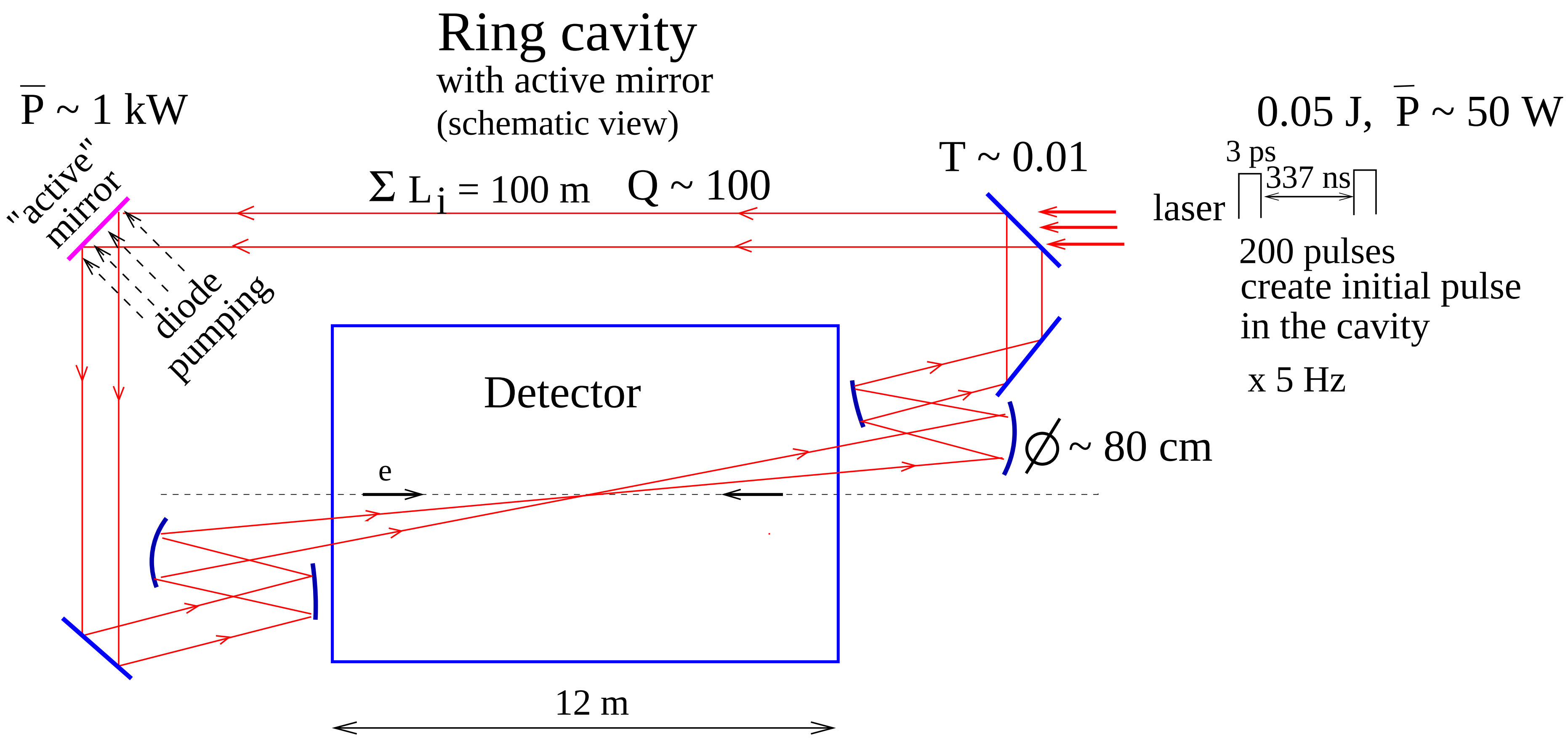
"External" optical cavity at TESLA

$$P_{cavity} = QP_{laser}, \; Q \sim 50\text{-}100$$

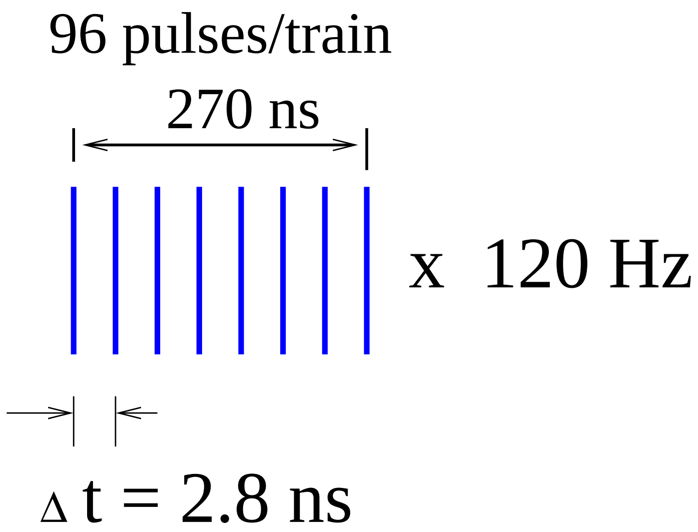


In this scheme the required tolerances $\Delta_L \sim \lambda/(2\pi Q)$, but as the feedback inside 1 msec train is possible (electro-optical delays), $\Delta_L \sim \mathcal{O}(0.1\lambda)$ may be sufficient!

"External" optical cavity with an active mirror

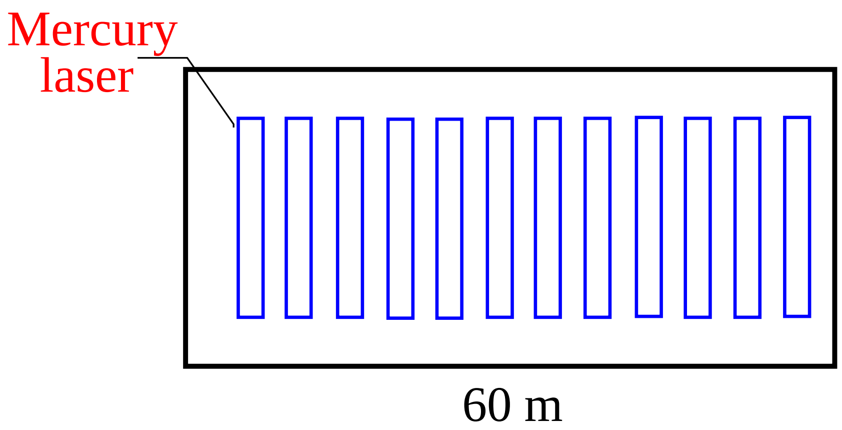


Lasers for NLC photon collider



$A_{flash} \sim 1.5$ J,
duration $\tau \sim 2$ ps,
$\lambda \sim 1$ μm.

NLC Laser Plant



It is based on the Mercury lasers developed for fusion

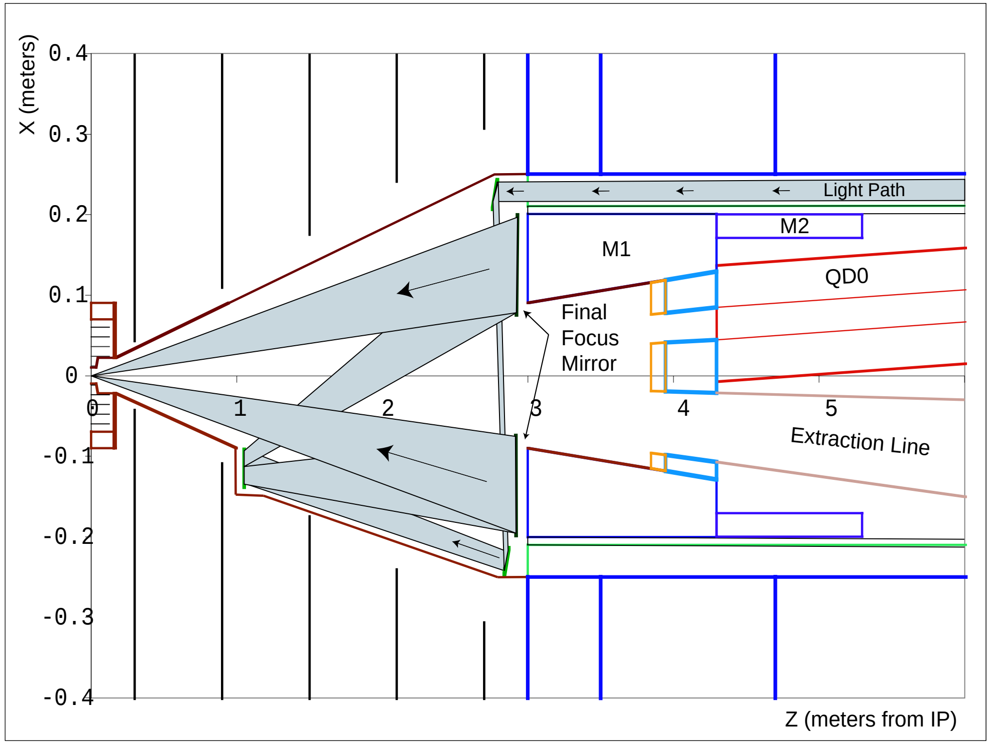
One laser produces:

- 100 − 200 J is splitted to 96 pulses with 2.8 ns delays
- 10 Hz rep. rate
- 10% efficiency, diode pumping
- 2−10 ns −> 2 ps
- 1 µm wavelength (Yb:S−FAP)

12 Mercuries required for NLC, ~ $ 100 − 200 M

Laser optics

at the NLC Interaction Region



The final focusing mirror of 40 cm diameter are situated at the diatance 4 m form the IP. It has the hole with 7 cm radius for incoming beams and outgoing disrupted beams.

This is one pass laser system

Experimentation

Main difference between c-LC and w-LC photon colliders is $\gamma\gamma \rightarrow hadron$ background. The average number of such events is about one per bunch crossing.

At c-LC each bunch collision is seen separately.

In w-LC the train is very short and the calorimeter will integrate a whole train. However, in Si-W callorimeter, considered for LC, 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 ns resolution. Detail simulation of this technology for the warm photon collider environment is needed.

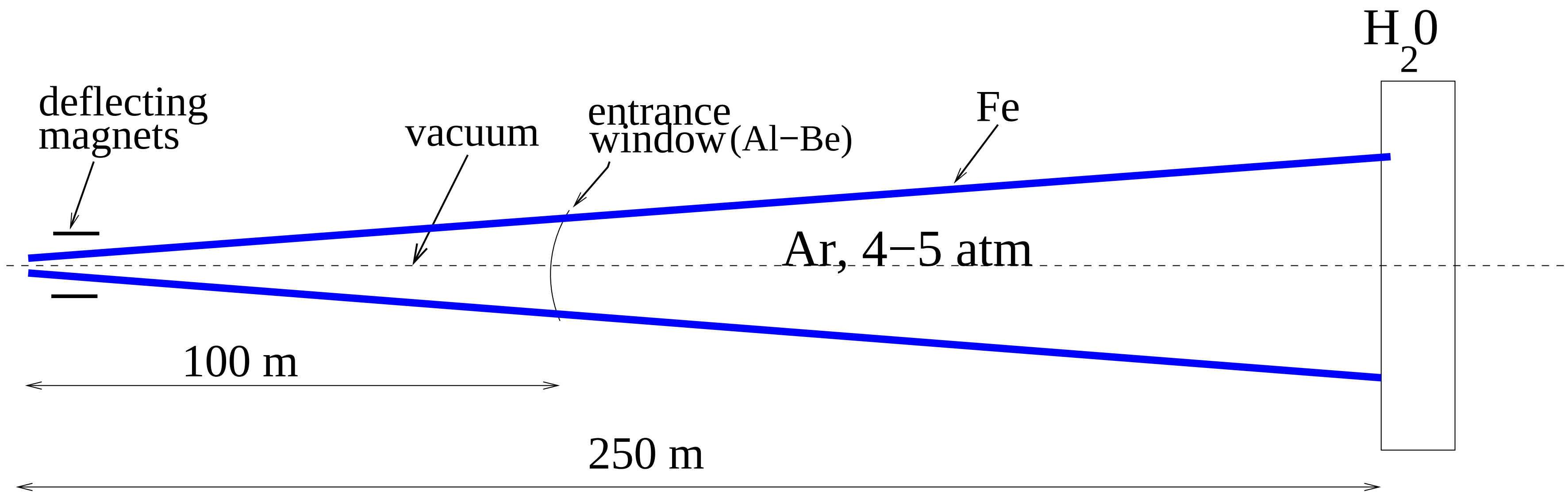
The beam dump

The beams at linear colliders are very narrow and powerful (the Compton photon beam at photon collider is always narrow, the electron beam is narrow only when it is not collidered with the opposing beam).

The problem of the beam dump for the electron beam has been solved both for NLC and TESLA. At TESLA the situation is more severe because 3000 beams hit the beam dump during a short time (compared with the cooling time). In order to avoid the local overheating electron beams are swept (one cicle during the train duration) by deflecting magnets. However, this scheme does not work for photons.

Below we present a scheme of the beam dump for the photon collider at TESLA-like collider.

The beam dump for TESLA (V.Telnov, L.Shekhtman)



The deflecting magnets rotate the electron beam (R=0.5-1cm at 100 m) in order to reduce local temperature at the entrance window. Energy deposition by photons in the entrance window is small.

A gas volume (Ar at P=3-5 atm) serves for conversion of photons and broadening of the shower before the water dump.

Simulation results

Maximum local ΔT in the water dump after passage of the train from 250 GeV photons is 75,50,25° at 3,4,5 atm Ar, respectively (and by a factor of 2 lower from electrons).

Maximum local ΔT at the exit Be-Ar (may be other material) window is small, $\sim 10^\circ$.

The maximum ΔT at the entrance Be-Al window is about 40° for $\sigma_{\theta_x} = 3 \times 10^{-5}, \sigma_{\theta_y} = 10^{-5}$ and R=0.5 cm (sweeping radius at the window). For the removal of the heat the thermal conductivity is sufficient (gas cooling can be added if necessary).

Note, the problem of the stress in solid materials in cold-LC beam dump is not important because the train duration is much longer than the decay time of local stress ($r/v_{sound} \sim 1\ \mu s$). It is more serious for warm-LC with short train.

The flux of neutrons at the IP is about 10^{11}/cm^2 for 10^7 s, some optimization is possible.

Conclusions

The luminosity at cold LC can be higher by a factor of 2 for present projects of injectors (damping rings).

A laser system is more elegant for c-LC (optical cavity) , but one pass laser system for w-LC is more developed (due to LLNL).

The problem of the hadronic background is much easier for c-LC, but it can be solved for w-LC as well.

Beam dump can be done for both project.

LC politicians should not ignore photon colliders, it also needs attention, development, optimization and inclusion to the LC project from the very beginning.