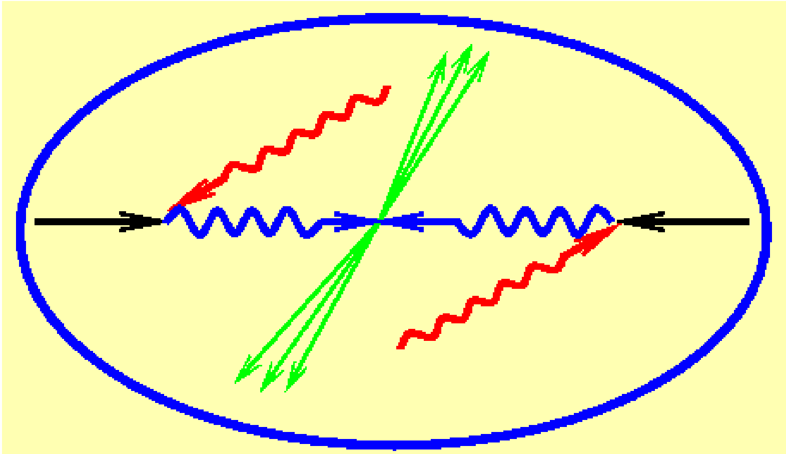

Ultimate parameters of the Photon Collider at ILC

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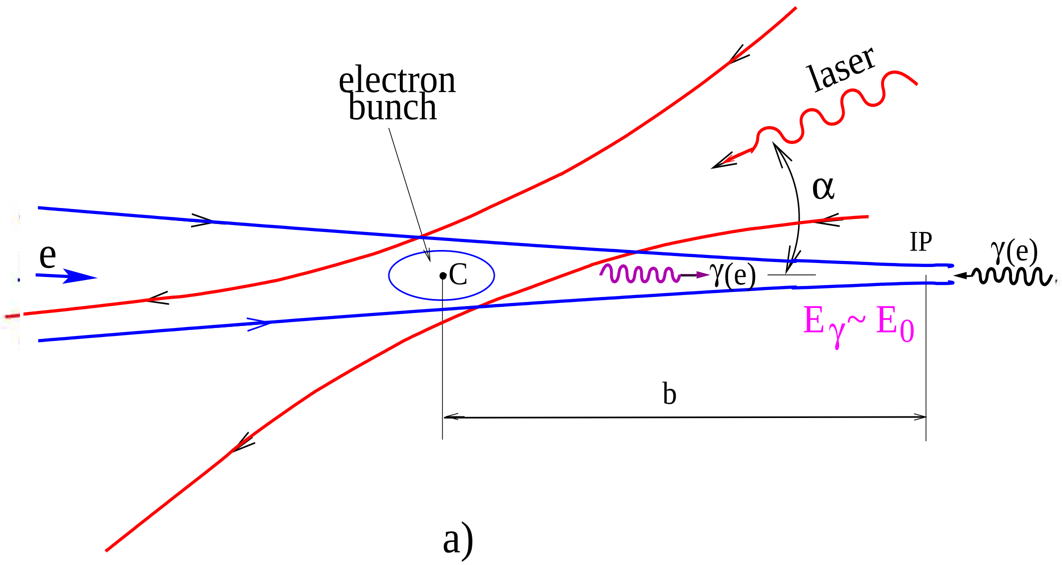
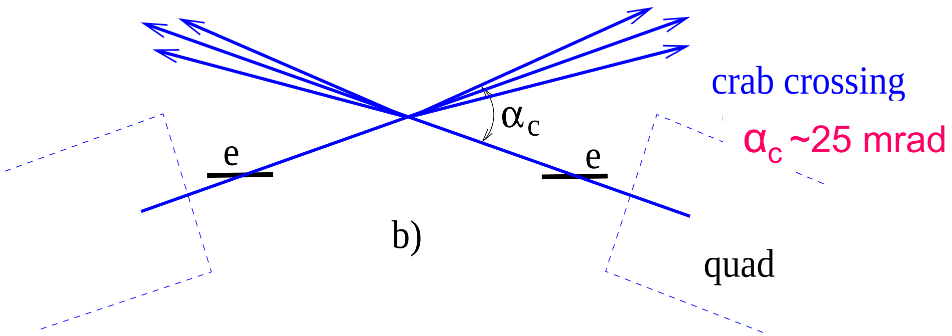
Scheme of $\gamma\gamma$, γe collider



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

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

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



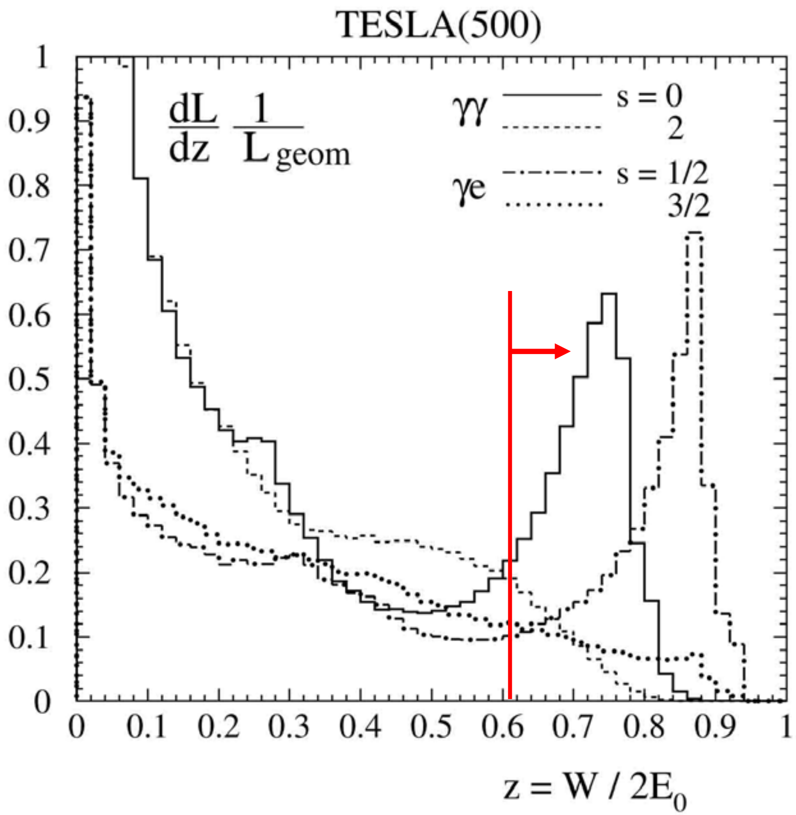
$x = 4.8$ is the threshold for
$\gamma\gamma_L \to e^+e^-$ at conv. reg.

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

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

Luminosity spectra

(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 nominal ILC parameters

$L_{\gamma\gamma}(z>z_m)$ ~(0.17-0.6-?) L_{e+e-}(nom)

(but cross sections in $\gamma\gamma$ are larger by one order!)

First number - nominal beam emittances

Second - with optimized DR

Third – a dream

For γe it is better to convert only one electron beam, in this case it will be easier to identify γe reactions and the γe luminosity will be larger.

Physics motivation: summary

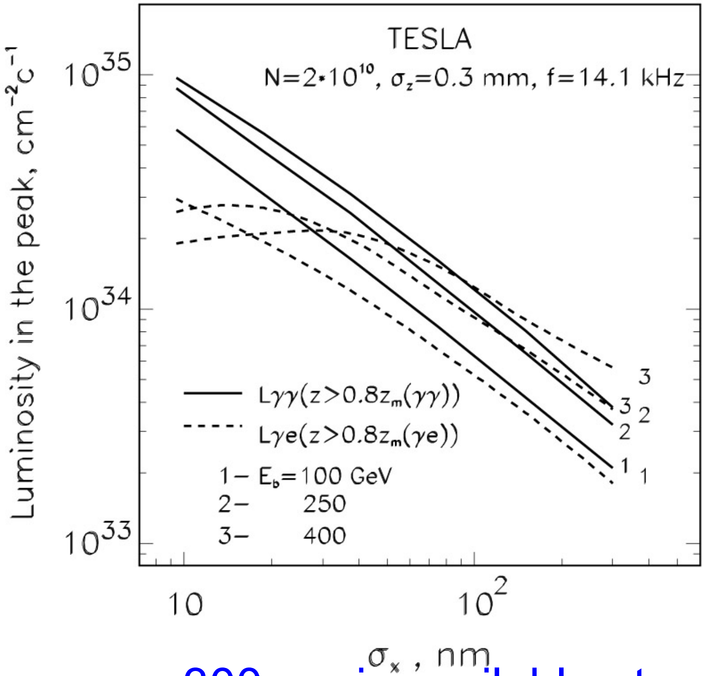
In $\gamma\gamma$, γe collisions compared to e^+e^-

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 rather moderate additional cost.

Factors limiting $\gamma\gamma,\gamma e$ luminosities

Collision effects:
- Coherent pair creation
- Beamstrahlung
- Beam-beam repulsion



On the right figure:
the dependence of $\gamma\gamma$ and γe luminosities in the high energy peak vs the horizontal beam size.

At the ILC nominal parameters of electron beams σ_x ~ 300 nm is available at $2E_0$=500 GeV. Having beams with smaller emittances one could obtain much higher $\gamma\gamma$ luminosity. Physics does not forbidden 30 times increase of the luminosity. Beside difficulty of obtaining small emittances some other technical problem may be important at very small σ_x such as stability of the crab-crossing tilt.

γe luminosity in the high energy peak is limited by beamstrahlung and beam repulsion.

So, one needs: ε_{nx}, ε_{ny} as small as possible and β_x , $\beta_y \sim \sigma_z$

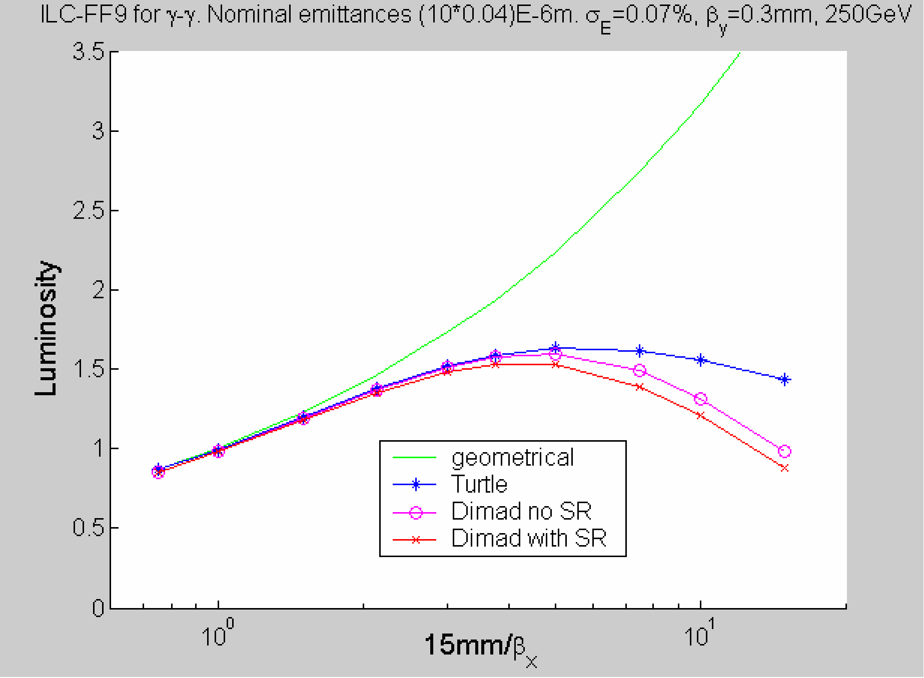
β-functions

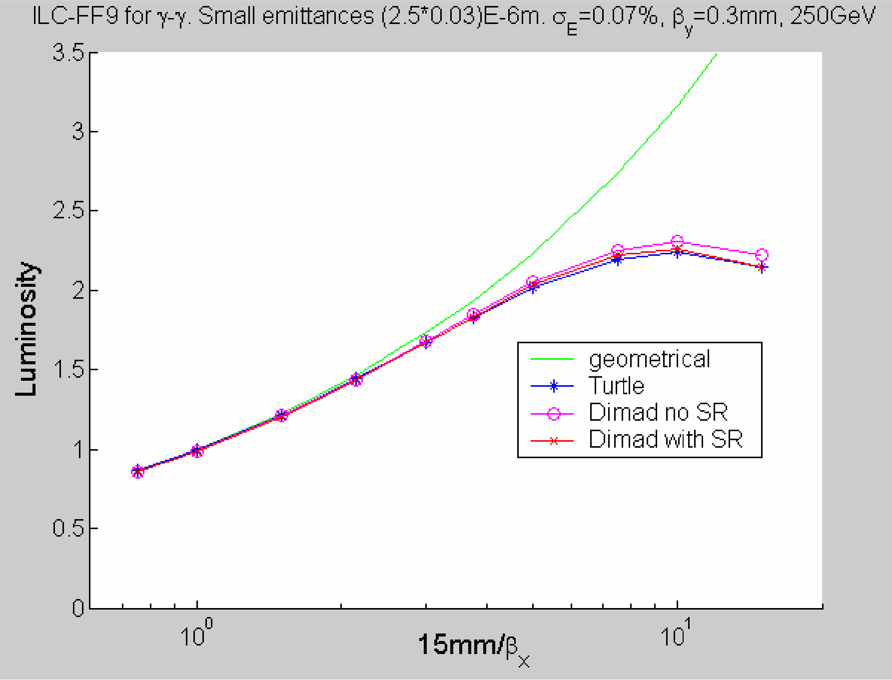
There is no problems to make $\beta_y=\sigma_z$ or even several times smaller, but there is a problem with reducing β_x due to chromo-geometric abberations.

Minimum value of β_x depends on the emittances (A.Seryi).

$\varepsilon_{nx}=1\cdot10^{-6}$ m $\rightarrow\beta_x^{eff}\sim 5$ mm $\qquad\qquad$ $\varepsilon_{nx}=0.25\cdot10^{-6}$ m $\rightarrow\beta_x^{eff}\sim 2.2$ mm

nominal





Emittances

Nominal ILC emittances

$\varepsilon_{nx}=10^{-5}$ m·rad, $\varepsilon_{ny}=4\times10^{-8}$ m·rad. Smaller emittances are not needed for *e+e-* due to beam-beam collision effects (beamstrahlung and instability).

For such emittances the minimum effective $\beta_x \sim 5$ mm

With TESLA damping ring optimized for $\gamma\gamma$ (W.Decking) we had at the IP $\varepsilon_{nx}=0.25\times10^{-5}$ m·rad, $\varepsilon_{ny}=3\times10^{-8}$ m·rad and min. effective $\beta_x \sim 2.2$ mm.

Similar emittances reported S.Mishra at LCWS04. With such emittances the geometric e^-e^- luminosity is larger than with the nominal ILC parameters by a factor of 3.5!

This is a large factor. It is desirable to decrease emittances, especially ε_{nx} , as much as it is possible

According to A. Wolski (at Snowmass 2005) such reduction of emittances in damping rings is possible by adding more wigglers, smaller damping time suppresses IBS (intra-beam scattering), but this possibility was not studied yet.

Comparison of $L_{\gamma\gamma}$ and L_{e+e-}

At the nominal ILC parameters $L_{e+e-}=2\cdot10^{34}$ cm^{-2}c^{-1}. For same parameters, CP-IP distance b=1 mm and $t/\lambda_c=1$ $L_{\gamma\gamma}(z>0.8z_m)=3.4\cdot10^{33}$ or

$$L_{\gamma\gamma} / L_{e+e-} = 0.17$$

If one reduces somewhat emittances:

$\varepsilon_{nx}=10^{-5} \rightarrow 0.5\cdot10^{-5}$; $\varepsilon_{ny}=4\ 10^{-8} \rightarrow 3\cdot10^{-8}$ and $\beta_x=5 \rightarrow 3.7$ mm

then $L_{\gamma\gamma} / L_{e+e-} = 0.32$ (0.3 in TESLA TDR).

Optimistically, $\varepsilon_{nx}=10^{-5} \rightarrow 0.25\cdot10^{-5}$ ($\beta_x=5 \rightarrow 2.2$ mm)

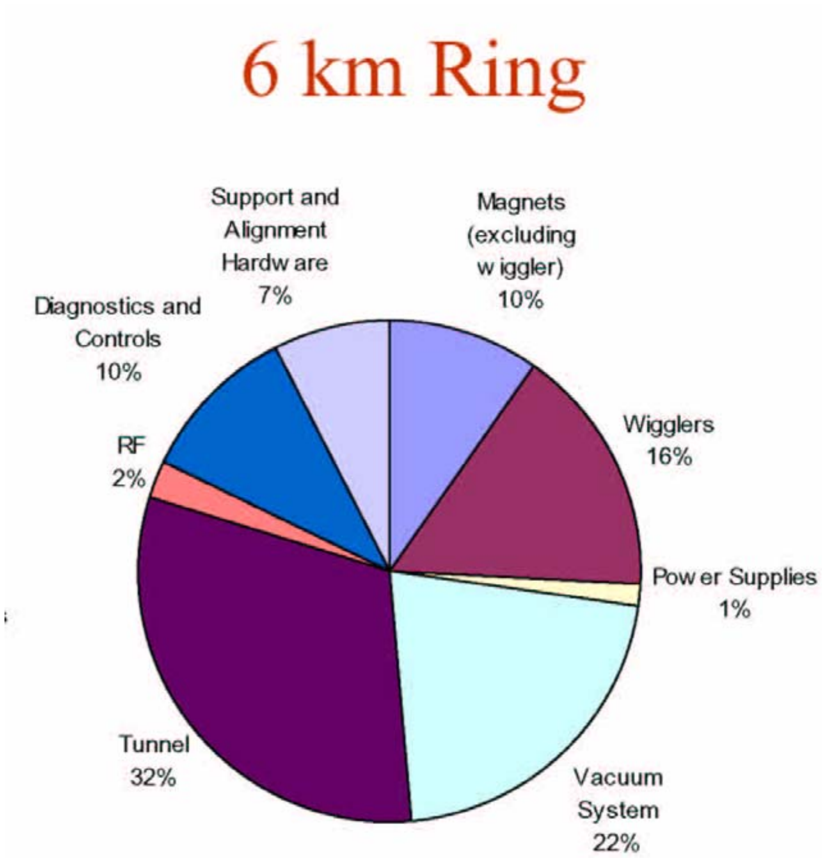
then $L_{\gamma\gamma} / L_{e+e-} = 0.59$

Note, cross sections in $\gamma\gamma$ are larger than in e+e- by a factor of 10.

So, even in the worst (nominal) case the number of events in $\gamma\gamma$ collisions is larger than in e+e-, but the increase of the $\gamma\gamma$ luminosity by an additional factor 2 – 3 is quite possible by optimizing damping rings.

Relative cost of DR components

(A.Wolski, Snowmass2005)



It seems, one can add more wigglers. It is not easy to estimate the decrease of the ε_{nx} because the IBS rate also changes. Optimization of the DR lattice can also suppress IBS, so it should be a global optimization of DRs.

How much we can decrease the damping time and what is the limit on emittances in the wiggler dominated regime?

For wigglers $$\varepsilon_{nx} \sim 3.3 \cdot 10^{-11} B_0^3(T) \lambda^2(cm) \beta_x(m) \quad m$$

$$\tau_d = \frac{3m^2c^3}{r_e^2 E B_0^2} = \frac{5.2 \cdot 10^{-3}}{E(GeV) B_0^2(T)} \quad \sec$$

If wigglers fill 1/3 of DR, then for B_0=2 T (permanent magnets), E=5 GeV, one gets $\tau = 7.5 \cdot 10^{-4}$ sec, that is about 20 times smaller than the damping time in present designs. It can be even shorter with SC wigglers.

For λ=10 cm and β_x=5 m the emittance $\varepsilon_{nx} = 1.3 \cdot 10^{-7}$ m, that is 60 times smaller than the present nominal emittance.

So, it seems there are a lot of unused resources for decreasing the damping time and thus decreasing emittances in each x,y directions and β_x. Until β_x and σ_y are larger than there limits (σ_z and 1 nm) there is a strong dependence of luminosity on the emittances $L \sim 1/\mathrm{sqrt}(\varepsilon_x \varepsilon_y \beta_x)$. The increase of the luminosity by a factor of 10 is not excluded after essential modification of damping rings! This need more RFpeak power, but this problems is solvable, the tune shift due to the space charge may be not important due to the strong damping.

It looks promising and needs a serious consideration by DR experts.

The optimistic goal for the photon collider at 2E=500 GeV corresponding to the increase of $L_{\gamma\gamma}$ by a factor of 10 compared to the luminosity with the present DR designed for e+e-:

$\varepsilon_{nx}=1.5\cdot 10^{-6}$ m, $\varepsilon_{ny}=0.7\cdot 10^{-8}$ m,

$\beta_x=1.5$ mm, $\beta_y=0.3$ mm,

$\sigma_x=67$ nm, $\sigma_y=2$ nm

$N=2\cdot 10^{10}$, f=14 kHz,

which gives at 2E=500 GeV, $L_{geom}=3.2\cdot 10^{35}$,

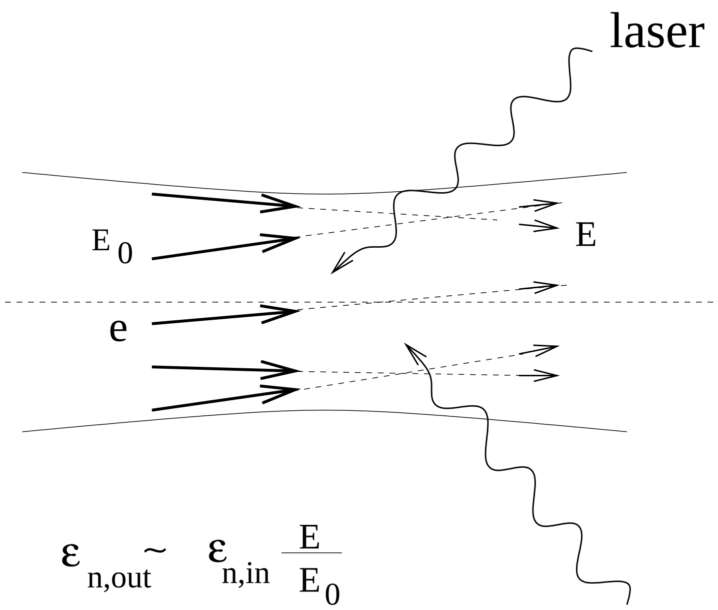
$L_{\gamma\gamma}(z>0.8z_m) \sim 3\cdot 10^{34}$ $\mathrm{cm}^{-2}\mathrm{s}^{-1} \sim 1.5\ L_{e+e-}$.

One example of physics

$\gamma\gamma \to HH$, the Higgs self-coupling

The cross section σ~0.2-0.4 fb. With above luminosity one will get about 180-360 events (before any cuts) per one year. About half of the cross section of this process near the threshold is connected with the Higgs self-coupling. The accuracy will be better than in e+e- collisions.

Laser cooling



$$\varepsilon_n(\min) = \frac{3}{10}\frac{\lambda_c}{\lambda}\beta$$

$$\lambda_c = h/mc = 2.4 \cdot 10^{-12} m$$

Advantages of shorter laser wavelength:

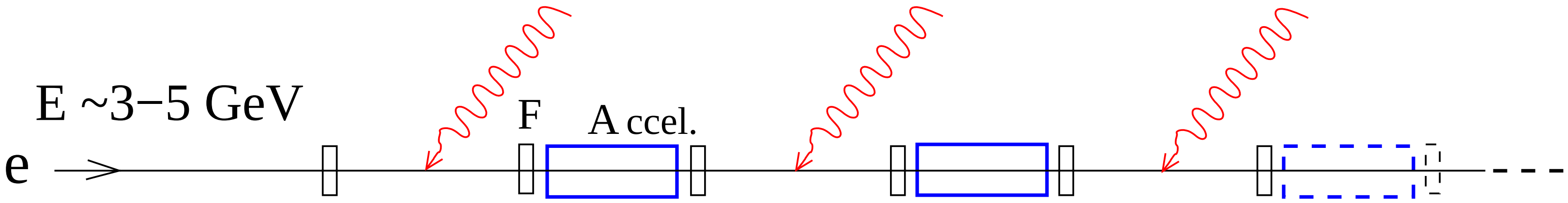
- required flash energy prop. to λ
- there are powerfull lasers with $\lambda \sim 1\ \mu m$

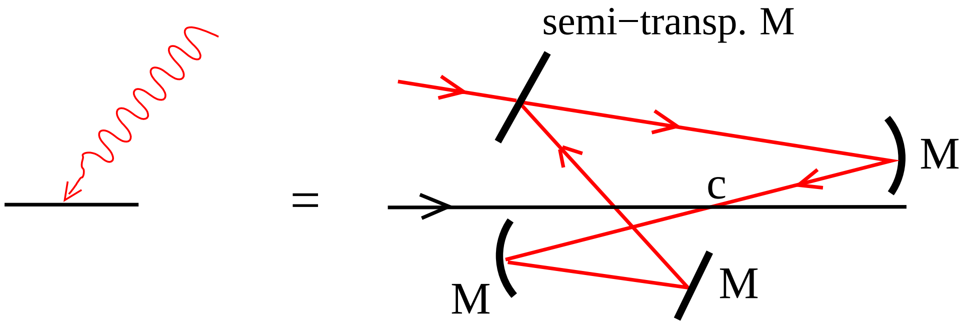
Advantages of longer laser wavelength:

- $\varepsilon_n \sim \beta/\lambda$ (one can use longer β-function, smaller abberations)
- $\sigma_E/E \sim 1/\sqrt{\lambda}$
- depolarization $d\zeta/\zeta \sim 1/\lambda$

For $\lambda > 10\ \mu m$ one can make a continuous cooling system with multiple cooling sections and semi-continuous reacceleration. There is no detailed accelerator study yet.

A possible scheme





Cooling is done after the bunch compression. Unfortunately, at ILC the distance between bunches is large (100 m) which needs long cavities. May be a special DR can be constructed with the energy spread about 5% at 5 GeV (0.25% at E=100 GeV).
The ring can decrease also the number of cooling sections.

σ_z	mm	0.3
E_0	GeV	5
λ	μm	10
ξ^2		1
#damp.length		4
$\varepsilon_0/\varepsilon$		50
#coll. section		100
#beam/sect		4
total energy of laser flash	kJ	1.5
rep.rate	kHz	10
aver.P in all cavities	MW	15
cavity Q		250
average laser power	kW	100
laser efficiency	%	5
wall plug power	MW	2
total length	km	~1.5

This system is about 100 times more powerful than needed for $e \to \gamma$ conversion at the photon collider

Conclusion

- Using a special wiggler dominated DR with a short damping time hopefully one can get a considerable increase the $\gamma\gamma$ luminosity, up to one order of magnitude. How much it cost?
- Same modification of DRs can give some increase the e+e- luminosity though much less than for $\gamma\gamma$.
- Laser cooling system can increase the $\gamma\gamma$ luminosity by a factor of 30, but it is too early to consider it seriously.

The damping ring with a short damping time is very promising for the ILC and needs a detail study.