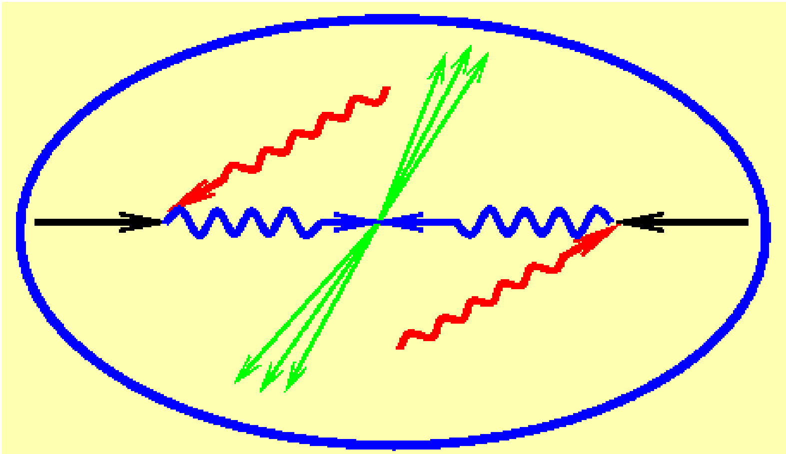

Issues with current design for e^+e^- and $\gamma\gamma$

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PHOTON-2013, Paris, May 23

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- ❖ Limitation on the luminosity of e^+e^- storage rings due to beamstrahlung.
- ❖ Photon collider Higgs factories (remarks)

Limitation on the luminosity of e+e- storage rings due to beamstrahlung

- Introduction
- Constraint on beam parameters due to beamstrahlung at e+e- storage rings
- Head-on and crab-waist schemes
- Ultimate luminosities
- LC with recuperation?
- Storage ring with charge compensation?

Introduction

Observation of the Higgs(126) have triggered proposals of e+e- ring Higgs factories on 2E=240 GeV (A.Blondel and F.Zimmermann, arXiv:1112.2518) and 2E=240-500 GeV (K.Oide, Super-Tristan, Feb.2012) and then many others.

There were hopes that using a crab-waist scheme (as was proposed for Super B factory) the luminosity of the ring e+e- collider could be higher than at linear colliders by a factor 20 at 2E=240 GeV and similar at 2E=500 GeV.

However, it turned out that the luminosity of high energy e+e- storage rings is limited by beamstrahlung (radiation in the field of the opposing beam), V.Telnov, arXiv:1203.6563, March 2012, PRL 110,114801 (2013).

Beamstralung is very well known as limiting factor at linear colliders. At high energy storage rings it influence somewhat differently: emission of single high energy photons in the tail of the beamstrahlung spectra determines the beam lifetime, this put the limitation of beam parameters ($N/\sigma_x\sigma_z$) and thus on luminosity.

Beam lifetime due to beamstrahlung

The electron loses the beam after emission of beamstrahlung photon with an energy greater than the threshold energy $E_{th}=\eta E_0$, where a *ring energy acceptance* $\eta \sim 0.01$.

These photons have energies mach larger than the critical energy

$$E_c = \hbar\omega_c = \hbar\frac{3\gamma^3 c}{2\rho},$$

The spectrum per unit length at $u = E_\gamma / E_c >> 1$

$$\frac{dn}{dx} = \sqrt{\frac{3\pi}{2}}\frac{\alpha\gamma}{2\pi\rho}\frac{e^{-u}}{\sqrt{u}}du, \qquad \alpha = \frac{e^2}{\hbar c} \approx \frac{1}{137}$$

The number of photons on collision length *l* with $E_\gamma > \eta E_0$

$$n_\gamma(E_\gamma \geq \eta E_0) \approx \frac{\alpha^2 \eta l}{\sqrt{6\pi} r_e \gamma u^{3/2}} e^{-u}; \quad u = \frac{\eta E_0}{E_c},$$

$l \approx \sigma_z / 2$ for head-on and $l \approx \beta_y / 2$ for crab-waist collisions

The corresponding beam lifetime depends exponentially on the critical energy (which is prop. to the beam field).

Using these simple formulas, one can estimate the critical energy of beamstrahlung photons (for the maximum beam field) corresponding to a beam lifetime of ~30 minutes:

$$u = \eta E_0/E_c \approx 8.5; \quad E_c \approx 0.12\eta E_0 \sim 0.1\eta E_0.$$

This estimate is done for typical collider parameters (R, E_0, σ_z), but the accuracy of this expression is quite good for any ring collider, because it depends logarithmically on these parameters (as well as on the lifetime).

The critical energy is related to the beam parameters as follows:

$$\frac{E_c}{E_0} = \frac{3\gamma {r_e}^2 N}{\alpha \sigma_x \sigma_z}. \qquad \text{where } r_e = e^2/mc^2.$$

This imposes a new restriction on the beam parameters

$$\boxed{\frac{N}{\sigma_x \sigma_z} < 0.1\eta \frac{\alpha}{3\gamma {r_e}^2}} \qquad *$$

This additional constraint on beam parameters should be taken into account in luminosity optimization.

It can be shown that the beam lifetime given the above conditions is determined by the emission of beamstrahlung photons with energies ~65 times greater than the average photon energy.

The rms beam energy spread due to beamstrahlung was compared to that due to synchrotron radiation in bending magnets. It was shown that in rings with large energy acceptance the energy spread due to beam-strahlung could be comparable to than due to SR; however, the lifetime is always determined by the emission of energetic single photons.

Head-on and "crab-waist" collision schemes

Below we consider two collision schemes: head-on and crab-waist.
In the crab-waist scheme the beams collide at an angle $\theta >> \sigma_x / \sigma_z$
This scheme allows a higher luminosity, if it is determined by the tune shift (beam-beam strength parameter characterizing instabilities).
For head-on collisions the tune shift ($\xi_y \leq 0.1-0.15$) and the luminosity

(1) $$\xi_y = \frac{N r_e \beta_y}{2\pi\gamma\sigma_x\sigma_y} \approx \frac{N r_e \sigma_z}{2\pi\gamma\sigma_x\sigma_y} \quad \text{for} \quad \beta_y \approx \sigma_z \qquad \mathcal{L} \approx \frac{N^2 f}{4\pi\sigma_x\sigma_y} \approx \frac{N f \gamma \xi_y}{2 r_e \sigma_z}$$

For the crab-waist scheme

(2) $$\xi_y = \frac{N r_e \beta_y^2}{\pi\gamma\sigma_x\sigma_y\sigma_z} \quad \text{for} \quad \beta_y \approx \sigma_x/\theta \qquad \mathcal{L} \approx \frac{N^2 f}{2\pi\sigma_y\sigma_z\theta} \approx \frac{N^2 \beta_y f}{2\pi\sigma_x\sigma_y\sigma_z} \approx \frac{N f \gamma \xi_y}{2 r_e \beta_y}$$

In the crab-waist scheme one can make $\beta_y \sim \sigma_y/\theta << \sigma_z$, therefore the luminosity is higher. Nf is determined by SR power. The only free parameters in L are σ_z (for head-on) and β_y (crab-waist), they are constrained by beamstrahlung condition

(3) $$\frac{N}{\sigma_x\sigma_z} < 0.1\eta \frac{\alpha}{3\gamma {r_e}^2}$$

Comparing (1),(2),(3) one can find the minimum beam energy when beamstrahlung becomes important.

For head-on collisions

$$\gamma_{\min} = \left(\frac{0.1 \eta \alpha \sigma_z^2}{6 \pi r_e \xi_y \sigma_y} \right)^{1/2} \propto \frac{\sigma_z^{3/4}}{\xi_y^{1/2} \varepsilon_y^{1/4}}$$

For "crab-waist" collisions

$$\gamma_{\min} = \left(\frac{0.1 \eta \alpha \beta_y^2}{3 \pi r_e \xi_y \sigma_y} \right)^{1/2} \propto \frac{2^{1/2} \beta_y^{3/4}}{\xi_y^{1/2} \varepsilon_y^{1/4}}$$

In the crab-waist scheme the beamstrahlung becomes important at much low energies because $\beta_y << \sigma_z$. For typical values of parameters E_{min}>70 GeV for head-on collisions and E_{min}>20 GeV for "crab-waist".

For considered colliders with $2E_0$>240 GeV beamstrahlung is important in both schemes.

Luminosities with account of beamstrahlung

For head-on collisions

$$\mathcal{L} \approx \frac{(Nf)N}{4\pi\sigma_x\sigma_y}, \; \xi_y \approx \frac{N r_e \sigma_z}{2\pi\gamma\sigma_x\sigma_y}, \; \frac{N}{\sigma_x\sigma_z} \equiv k \approx 0.1\eta\frac{\alpha}{3\gamma {r_e}^2} \qquad \sigma_y \approx \sqrt{\varepsilon_y\sigma_z}$$

Together these equations give

$$\mathcal{L} \approx \frac{Nf}{4\pi}\left(\frac{0.1\eta\alpha}{3}\right)^{2/3}\left(\frac{2\pi\xi_y}{\gamma r_e^5 \varepsilon_y}\right)^{1/3}$$

$$\sigma_{z,\mathrm{opt}} = \varepsilon_y^{1/3}\left(\frac{6\pi\gamma^2 r_e \xi_y}{0.1\eta\alpha}\right)^{2/3}$$

Luminosities with account of beamstrahlung

Similarly for the crab-waist collisions

$$\mathcal{L} \approx \frac{(Nf)N\beta_y}{2\pi\sigma_x\sigma_y\sigma_z}, \; \xi_y \approx \frac{Nr_e\beta_y^2}{\pi\gamma\sigma_x\sigma_y\sigma_z}, \; \frac{N}{\sigma_x\sigma_z} \equiv k \approx 0.1\eta\frac{\alpha}{3\gamma r_e{}^2} \qquad \sigma_y \approx \sqrt{\varepsilon_y\beta_y}$$

The corresponding solutions are

$$\mathcal{L} \approx \frac{Nf}{4\pi}\left(\frac{0.2\eta\alpha}{3}\right)^{2/3}\left(\frac{2\pi\xi_y}{\gamma r_e^5\varepsilon_y}\right)^{1/3}$$

$$\beta_{y,\mathrm{opt}} = \varepsilon_y^{1/3}\left(\frac{3\pi\gamma^2 r_e\xi_y}{0.1\eta\alpha}\right)^{2/3}$$

In the beamstrahlung dominated regime the luminosities in crab-waist and head-on collisions are practically the same! (difference $2^{2/3}$~1)

As soon as the crab-waist gives no profit at high energies, further we will consider only the head-on scheme.

The maximum luminosity with account of beamstrahlung

$$\mathcal{L} \approx h \frac{N^2 f}{4\pi\sigma_x\sigma_y} = h \frac{Nf}{4\pi}\left(\frac{0.1\eta\alpha}{3}\right)^{2/3}\left(\frac{2\pi\xi_y}{\gamma r_e^5 \varepsilon_y}\right)^{1/3}$$

where h is the hourglass loss factor, $f=n_b c/2\pi R$.

The SR power in rings $$P = 2\delta E \frac{cNn_{\rm b}}{2\pi R} = \frac{4e^2\gamma^4 cNn_{\rm b}}{3RR_{\rm b}}$$

Finally, the luminosity

$$\mathcal{L} \approx h \frac{(0.1\eta\alpha)^{2/3} PR}{32\pi^2\gamma^{13/3} r_e^3}\left(\frac{R_{\rm b}}{R}\right)\left(\frac{6\pi\xi_y r_e}{\varepsilon_y}\right)^{1/3}$$

In practical units

$$\frac{\mathcal{L}}{10^{34}\,{\rm cm^{-2}s^{-1}}} \approx \frac{100 h\eta^{2/3}\xi_y^{1/3}}{(E_0/100\,{\rm GeV})^{13/3}(\varepsilon_y/\,{\rm nm})^{\frac{1}{3}}}\left(\frac{P}{100\,{\rm MW}}\right)\left(\frac{2\pi R}{100\,{\rm km}}\right)\frac{R_{\rm b}}{R}$$

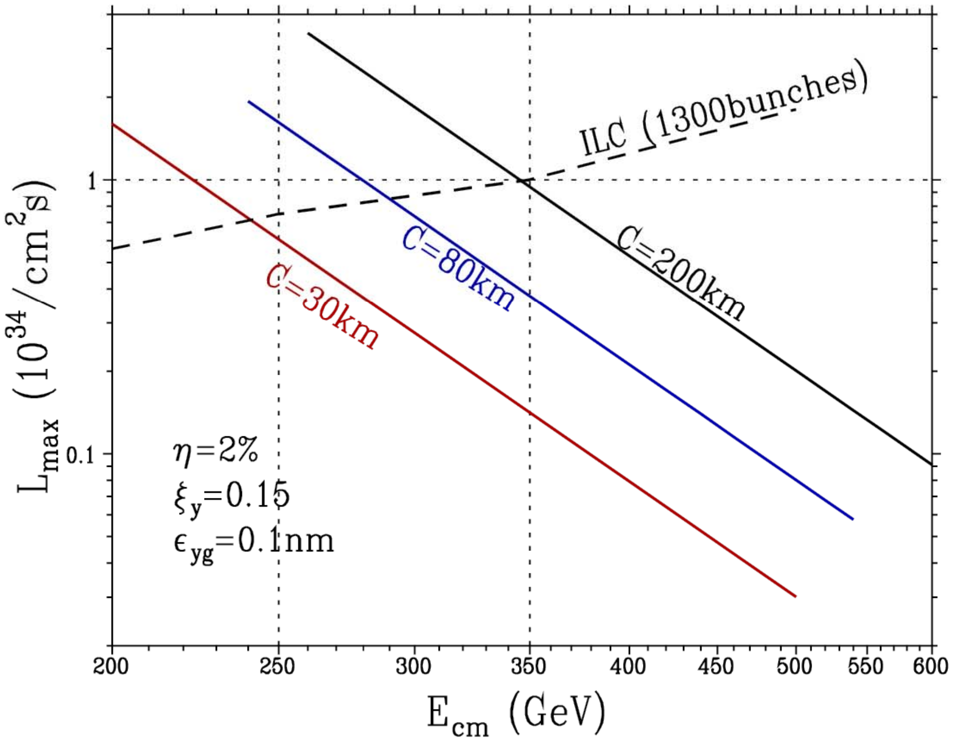
The beamstrahlung suppresses the luminosity by a factor $\sigma_z/\sigma_{opt}=(E_{min}/E_0)^{4/3}$ for the energies above E_{min}, which is about 70 GeV for head-on and 20 GeV for crab-waist schemes.

Luminosity vs. Energy

example with

- η=2%
- ξ_y=0.15
- ε_{gy}=0.1nm

P_{SR}=100 MW



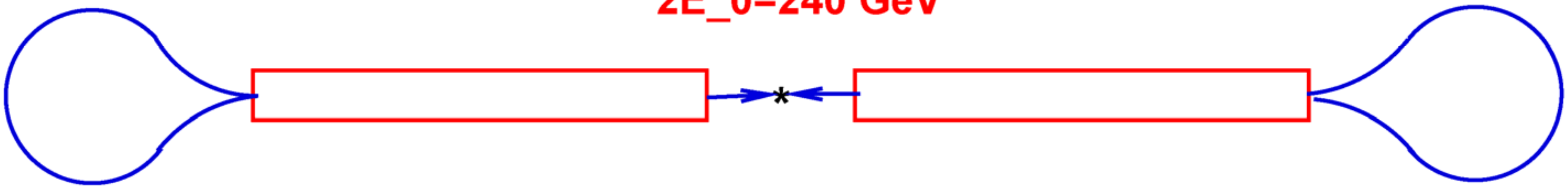
For 2E=240 GeV the luminosities (per one IP) of ring and linear colliders are comparable. But large ring colliders with 4 IP can provide by one order higher luminosity.

Thus, the luminosity of linear colliders is limited by wall-plug power, they are not energy-effective because each bunch is used only once.

The luminosity of high energy storage rings is also determined by wall-plug power due to severe synchrotron radiation.

Is there any solution of the problem?

CW Linear collider with a recuperation?



If η is the energy acceptance of the ring, the maximum energy of beamstrahlung photons should be ηE (not ηE_0). This reduce L by a factor of $(E/E_0)^{2/3}$~0.25. However, due to much lower SR losses (E^4/R) one can increase Nf by a very large factor and thus to increase the luminosity by 1-2 orders of magnitude (>10^{35}).

Unfortunately, there are many stoppers which kill this scheme:

1. Refrigeration power is about 150-200 MW (accel. grad. ~15 MeV/m, $Q=2\cdot10^{10}$)
2. Parasitic collision of beams inside the linac. One can separate beams (pretzel scheme), but the beam attraction leads to the beam instability.
3. The transverse wake field problem for beams shifted from the axis.
4. The energy difference between the head and tail becomes unacceptable after deceleration (beam loading helps during acceleration, but makes worse during deceleration).

That is a good idea, but technically impossible. LC schemes with recuperation were considered in 1970's and were also rejected.

Charge compensated e+e- +e+e- beams

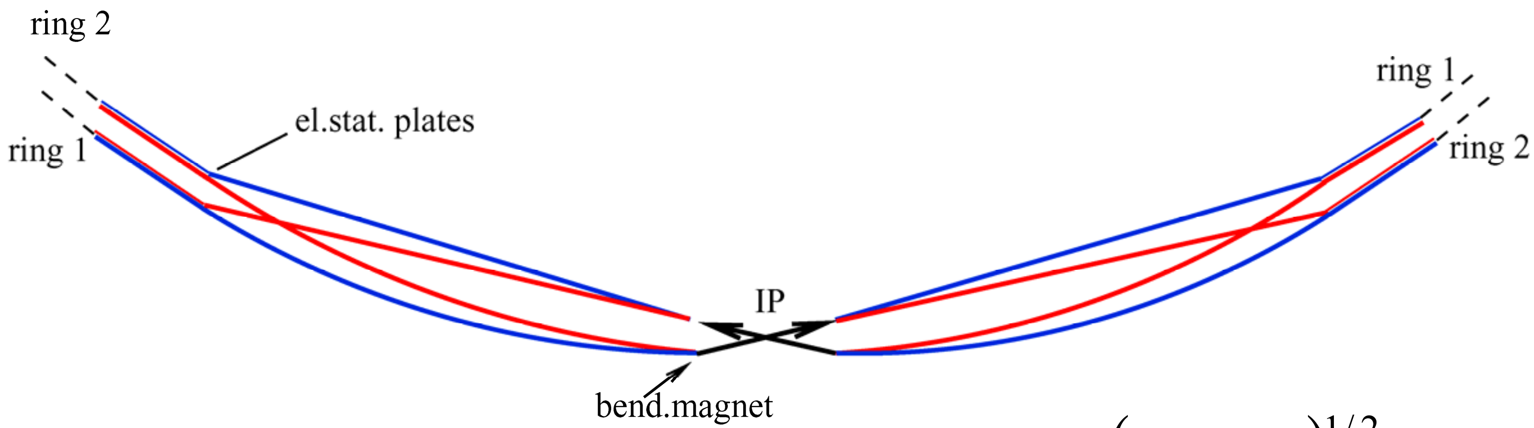
The idea to collide 4 beams (e+e- with e+e-) is more than 40 years old. Beams are neutral, there are no collision effects, sound nice.

Such 4-beam e+e- collider on the energy 2E~2 GeV, DCI, was build in 1970th in Orsay. There were hopes to increase the luminosity by a factor of 100 compared to the normal 2-beam e+e- case. But the result was confusing: the maximum luminosity was approximately the same. The reason - instability of neutral e+e- beams: small displacement of charges leads to the charge separation in opposing beam and thus to development of instability and the loss of the beam neutrality, appearance of tune shifts and corresponding resonances. The attainable beam-beam parameter ξ was approximately the same as without neutralization.

Charge compensation (cont.)

In our case we don't need to increase ξ, we want to suppress beam-strahlung. In the case of crab-waist collision this could give the increase of the luminosity by a factor of 20-30.

Scheme of a charge compensated crab-waist e+e- ring collider



The required degree of neutralization

$$\frac{\Delta N}{N} = \frac{(\xi_c / \xi_{nc})^{1/2}}{(L_c / L_{nc})^{3/2}}$$

If $\xi_c = \xi_{nc}$, then for the increase of the luminosity by a factor of 10 one needs ΔN/N=0.03, looks possible.

Main problem (stopper): SR in the combining bending magnet (that should be place between the IP and the final focus).

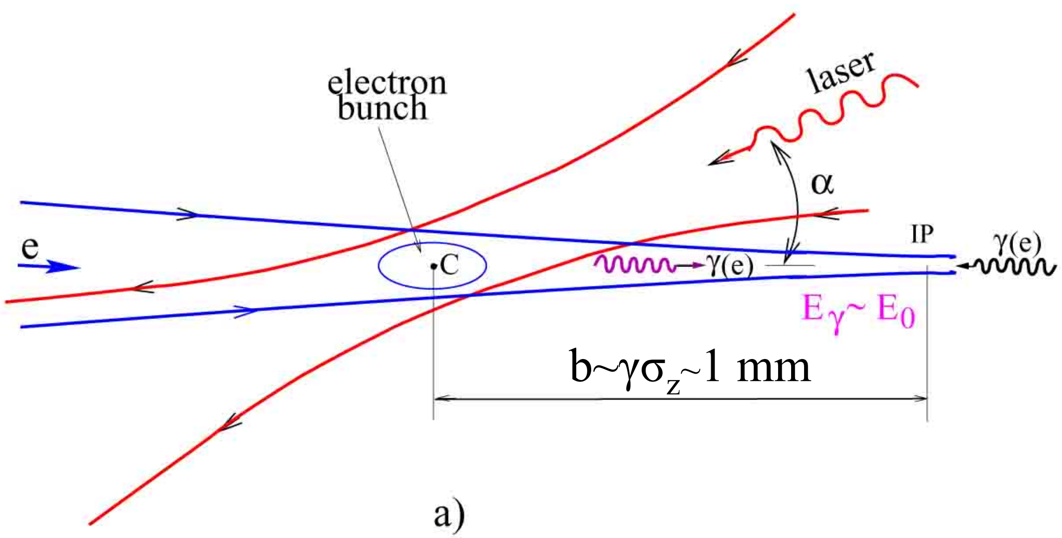
Photon colliders:
Higgs factories?

Contents

- Inroduction
- ILC
- CLIC
- SAPPHIRE and others
- Super γγ factory
- Conclusion

Scheme of $\gamma\gamma$, γe collider

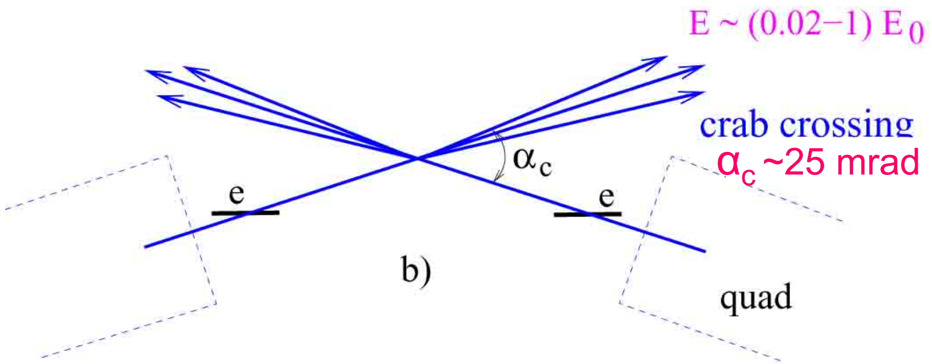
GKST 1981



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

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

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



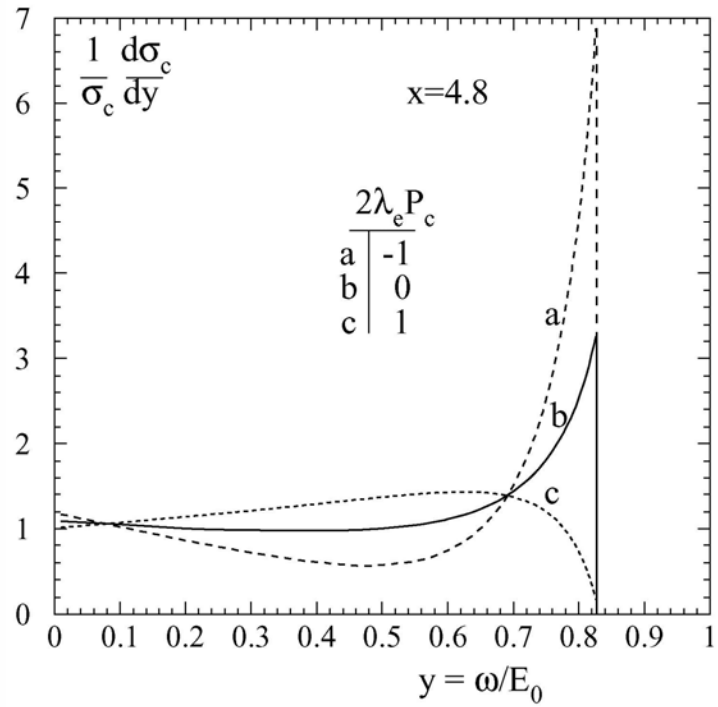
$x = 4.8$ is the threshold for
$\gamma\gamma_L \to e^+e^-$ at conv. reg.

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

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

Electron to Photon Conversion

Spectrum of the Compton scattered photons

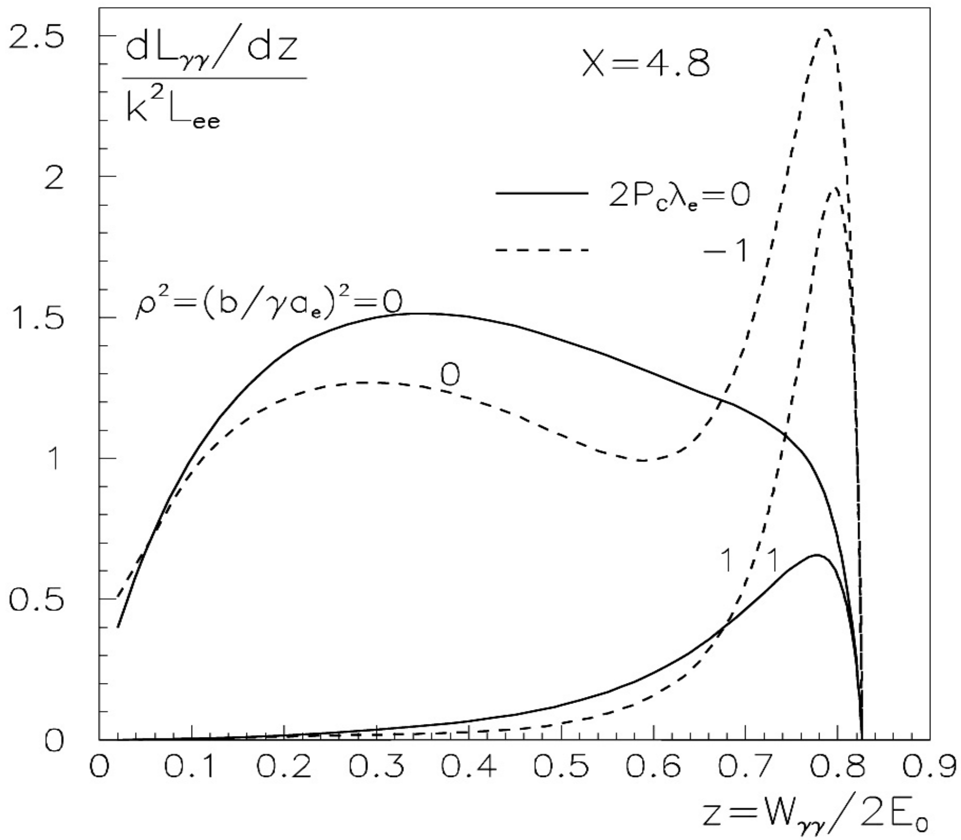


λ_e – electron longitudinal polarization
P_c – helicity of laser photons, $x \approx \frac{4E_0\omega_0}{m^2c^4}$

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

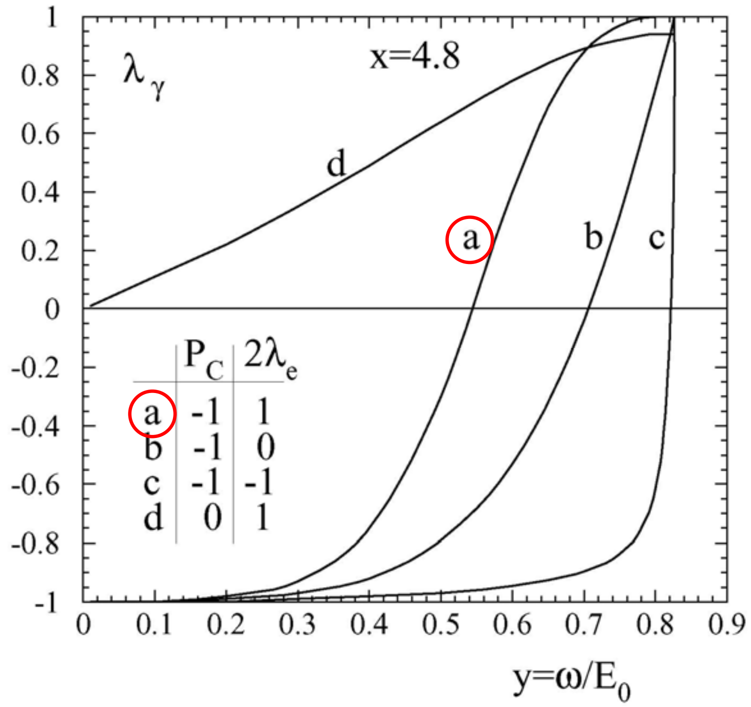
Ideal luminosity distributions, monohromatization

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



Electron polarization increases the γγ luminosity in the high energy peak up to a factor of ~3 (at large x).

Mean helicity of the scattered photons $(x = 4.8)$



Highest energy scattered photons are polarized even at λ_e=0 (see (b))

(in the case a) photons in the high energy peak have $\lambda_\gamma \approx 1$)

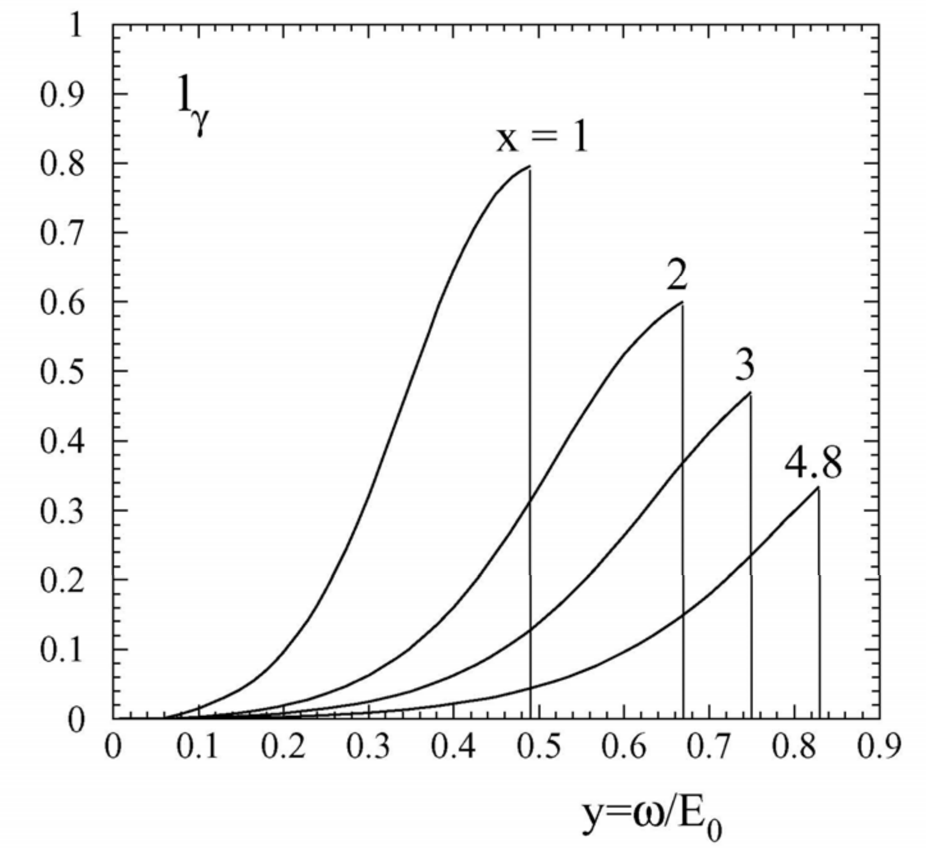
The cross section of the Higgs production

$$\sigma(\gamma\gamma \to h) \propto 1 + \lambda_1\lambda_2$$

The cross section for main backgound

$$\sigma(\gamma\gamma \to b\bar{b}) \propto 1 - \lambda_1\lambda_2$$

Linear polarization of photons



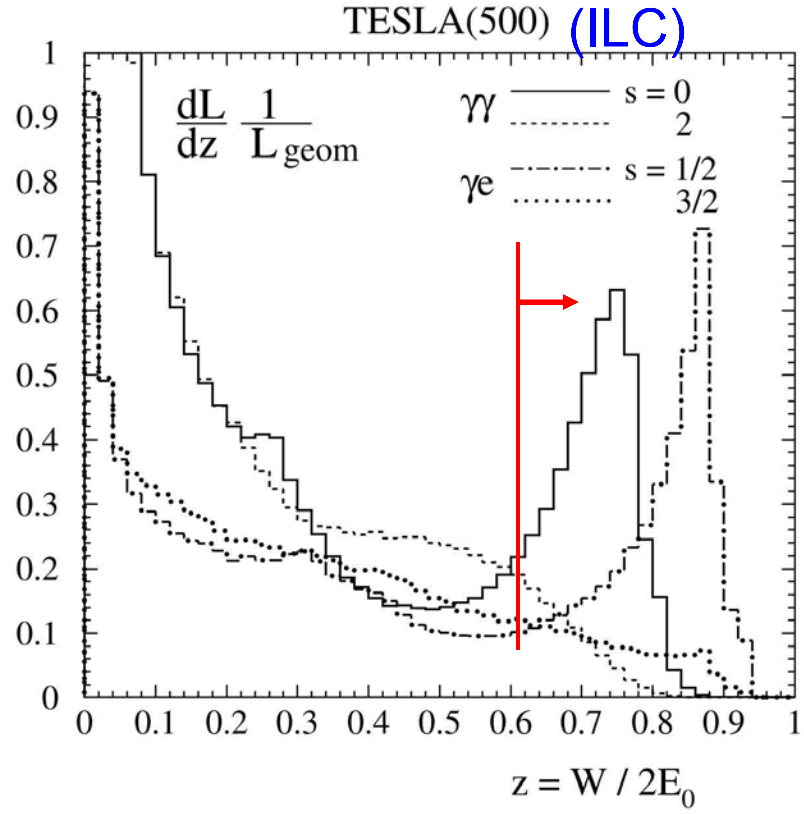
$\sigma \propto 1 \pm l_{\gamma 1} l_{\gamma 2} \cos 2\varphi$ ± for CP=±1

Linear polarization helps to separate H and A Higgs bosons

Realistic luminosity spectra ($\gamma\gamma$ and γe)

(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

$L_{\gamma\gamma}(z>0.8z_m)$ ~0.1 $L_{e\text{-}e\text{-}}$(geom)

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

Physics at PLC

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

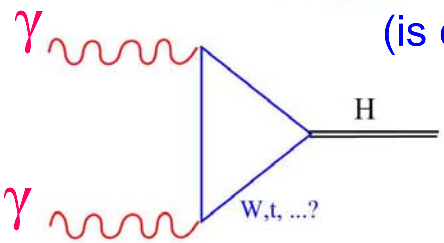
At present only light Higgs boson is discover.

Below I will just remind some gold-plated processes for PLC and model independent features.

Some examples of physics at PLC

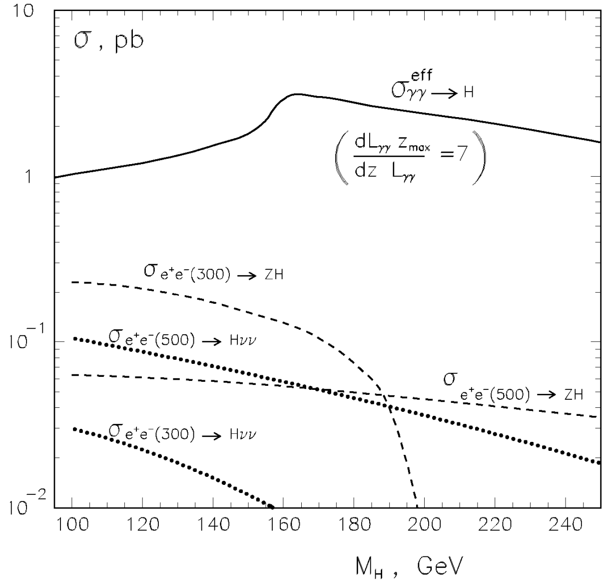
Higgs boson

(is considered for PLC since 1980th)



Very sensitive to heavy charge particles in the loop.

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



V.T,1999

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

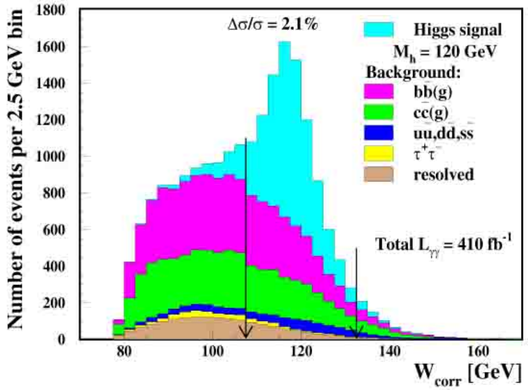
At ILC

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

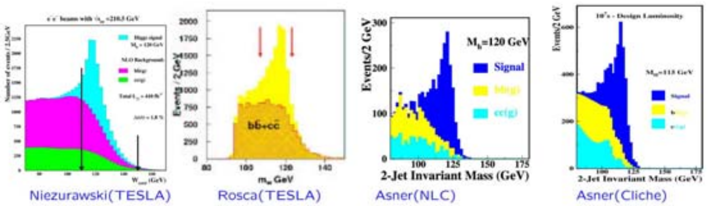
For M_H=115-250 GeV

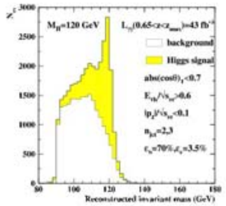
At nominal luminosities the number of Higgs in $\gamma\gamma$ will be similar to that in e+e-

realistic simulation P.Niezurawski et al



(previous analyses)





S.Soldner-Rembold
(thr first simulation)

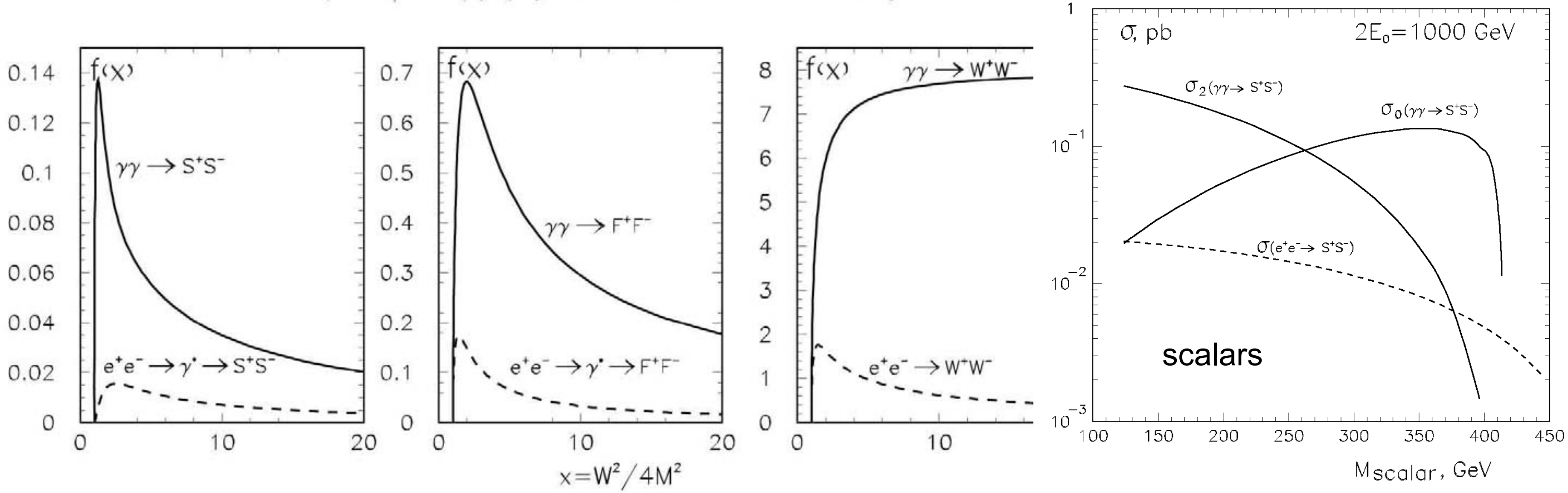
Charged pair production in e^+e^- and $\gamma\gamma$ collisions.

unpolarized beams

S (scalars), F (fermions), W (W-bosons);

$\sigma = (\pi\alpha^2/M^2) f(x)$, 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:

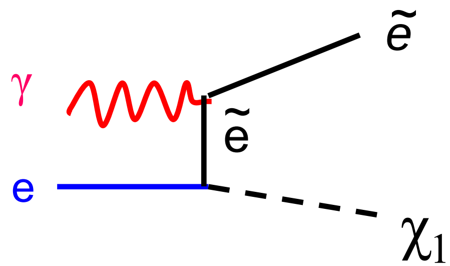
in e^+e^- collisions $M_{H,A}^{max} \sim E_0$ ($e^+e^- \to H + A$)
in $\gamma\gamma$ collisions $M_{H,A}^{max} \sim 1.6 E_0$ ($\gamma\gamma \to H(A)$)

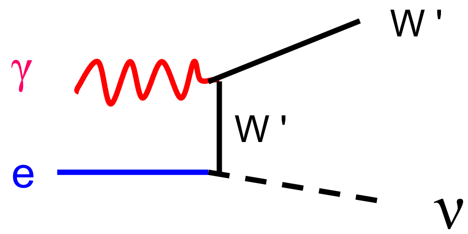
For some SUSY parameters H,A can be seen only in $\gamma\gamma$
(but not in e+e- and LHC)

Supersymmetry in γe

At a γe 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):

$$m_{\tilde{e}^-} < 0.9 \times 2E_0 - m_{\tilde{\chi}_1^0}$$





Measurement of the Higgs CP-properties

PLC in TESLA TDR, 2001

$$\sigma \propto 1 \pm l_{\gamma 1} l_{\gamma 2} \cos 2\phi,$$

where $l_{\gamma i}$ are the degrees of linear polarization and ϕ is the angle between $\vec{l_{\gamma 1}}$ and $\vec{l_{\gamma 2}}$, and the $\pm$ signs correspond to CP$= \pm 1$ scalar particles.

Measurement of CP violating asymmetry

$$\mathcal{A}_1 = \frac{|\mathcal{M}_{++}|^2 - |\mathcal{M}_{--}|^2}{|\mathcal{M}_{++}|^2 + |\mathcal{M}_{--}|^2}, \quad \mathcal{A}_2 = \frac{2Im(\mathcal{M}^*_{--}\mathcal{M}_{++})}{|\mathcal{M}_{++}|^2 + |\mathcal{M}_{--}|^2}.$$

$$T_- = \frac{N_{++} - N_{--}}{N_{++} + N_{--}} = \frac{\langle\xi_2\rangle + \langle\tilde{\xi}_2\rangle}{1 + \langle\xi_2\tilde{\xi}_2\rangle}\mathcal{A}_1,$$

$$T_\psi = \frac{N(\phi = \frac{\pi}{4}) - N(\phi = -\frac{\pi}{4})}{N(\phi = \frac{\pi}{4}) + N(\phi = -\frac{\pi}{4})} = \frac{\langle\xi_3\tilde{\xi}_1\rangle + \langle\xi_1\tilde{\xi}_3\rangle}{1 + \langle\xi_2\tilde{\xi}_2\rangle}\mathcal{A}_2,$$

Physics motivation for PLC

(independent on physics scenario)

(shortly)

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 (H,A in $\gamma\gamma$, charged and light neutral SUSY in γe)
4. higher precision for some phenomena ($\Gamma_{\gamma\gamma}$, CP-proper.)
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 the cost of rather small additional investments

Remark on Photon collider Higgs factories

Photon collider can measure
$\Gamma(H\to\gamma\gamma)$*Br($H\to$bb, ZZ,WW), $\Gamma^2(H\to\gamma\gamma)/\Gamma_{tot}$, CP properties.
e+e- can also measure Br(bb, cc, gg, $\tau\tau$, $\mu\mu$, invisible), Γ_{tot} .

Therefore PLC is nicely motivated in combination with e+e-: parallel work or second stage.

There were suggestions (H. Sugawara, 2009) to built a PLC Higgs factory as the ILC precursor, but it was not accepted by physics community mainly because a) e+e- physics case (for Higgs study) is stronger, 2) further delay of e+e-(~5 years)

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. Required laser technique is developed independently for many other applications based on Compton scattering. Recently LLNL started work on LIFE lasers for thermonuclear plant which seems very attractive (one pass laser).

Further developments need political decisions and finances.

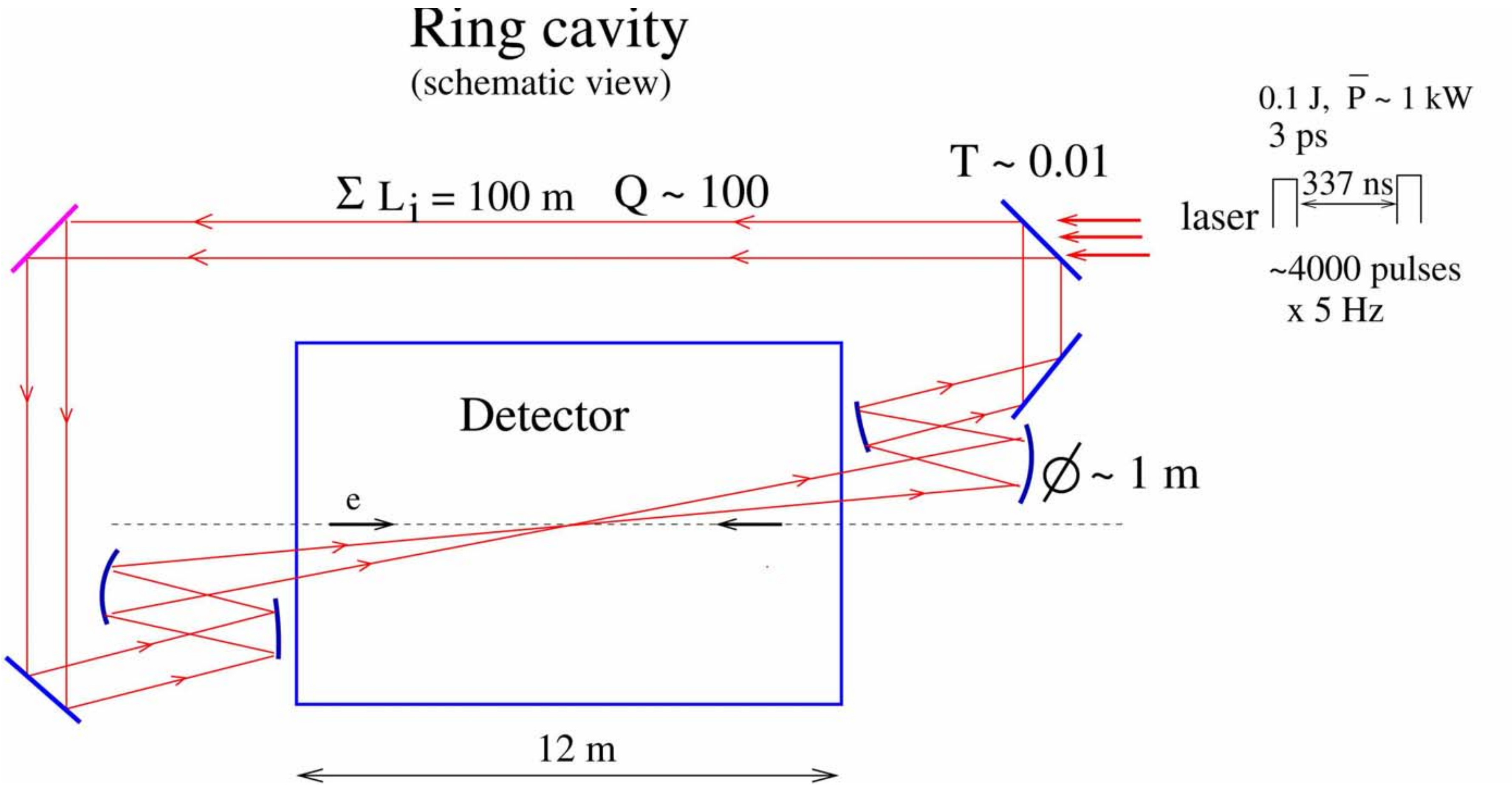
Requirements for laser

- 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

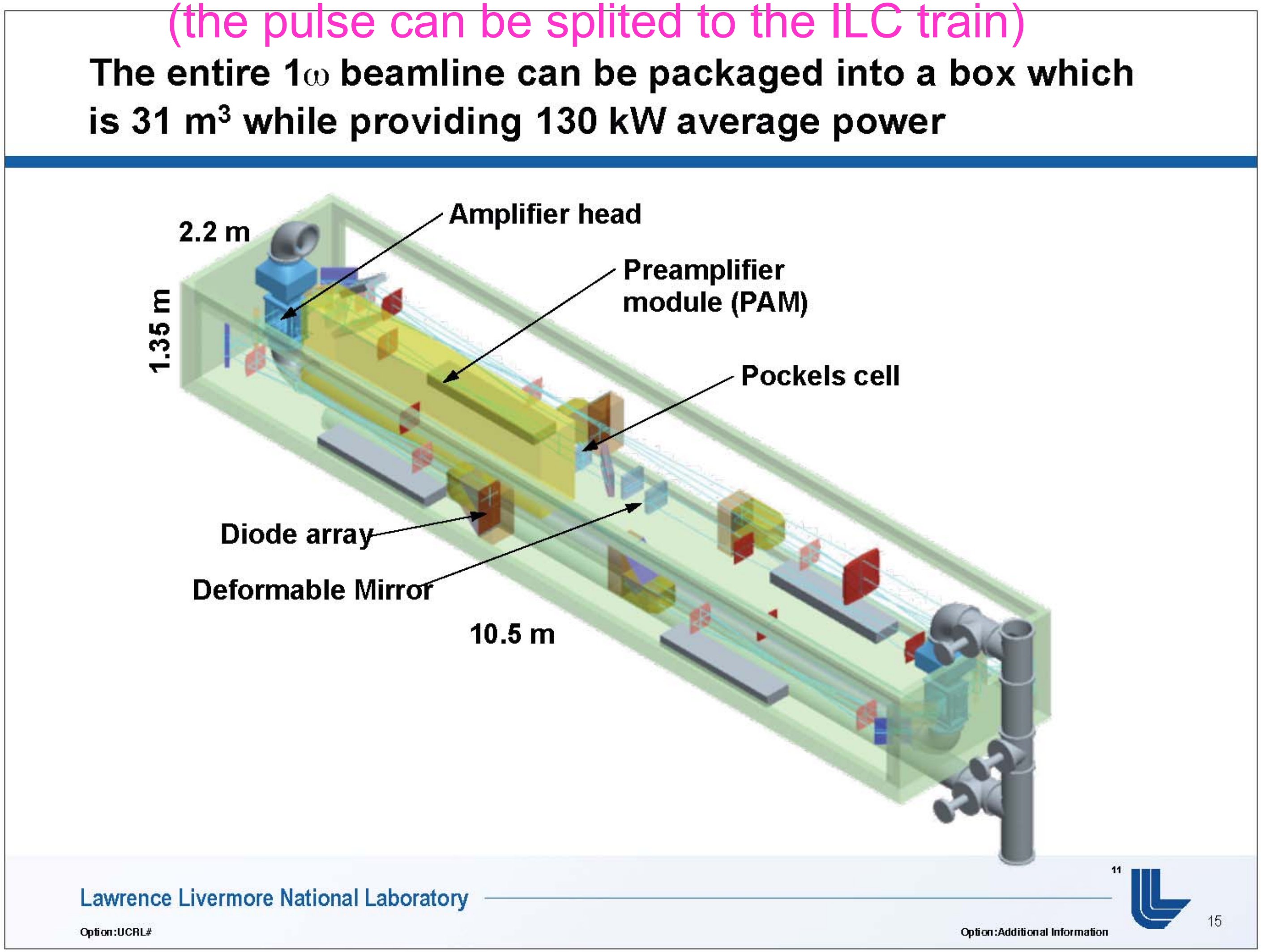


The cavity includes adaptive mirrors and diagnostics. Optimum angular divergence of the laser beam is ±30 mrad, A≈9 J (k=1), $\sigma_t \approx 1.3$ ps, $\sigma_{x,L}$~7 μm

Recently new option has appeared, one pass laser system, based on new laser ignition thermonuclear facility

Project LIFE, LLNL 16 Hz, 8.125 kJ/pulse, 130 kW aver. power

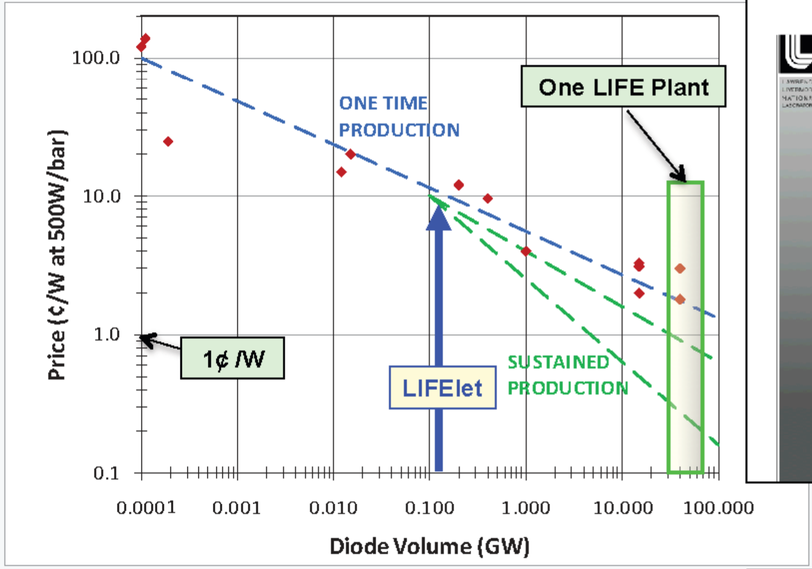
(the pulse can be splited to the ILC train)

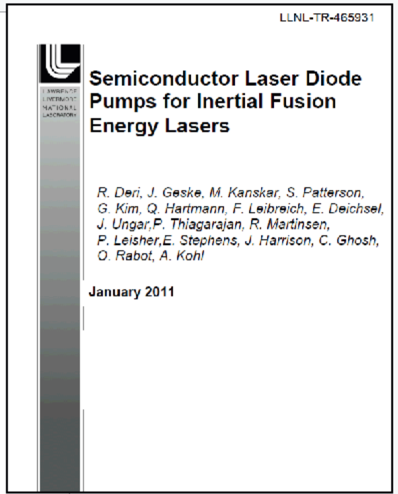


Laser diodes cost go down at mass production, that makes one pass laser system for PLC at ILC and CLIC realistic!

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




LLNL-TR-465931

Semiconductor Laser Diode Pumps for Inertial Fusion Energy Lasers

R. Deri, J. Geske, M. Kanskar, S. Patterson, G. Kim, Q. Hartmann, F. Leibreich, E. Deichsel, J. Ungar, P. Thiagarajan, R. Martinsen, P. Leisher, E. Stephens, J. Harrison, C. Ghosh, O. Rabot, A. Kohl

January 2011

- 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

Diode costs for 1 beamline ~ $2.3M

LIFElet (1st beamline) $0.1/W diodes for 1 beamline $13M

Lawrence Livermore National Laboratory

Option:UCRL#

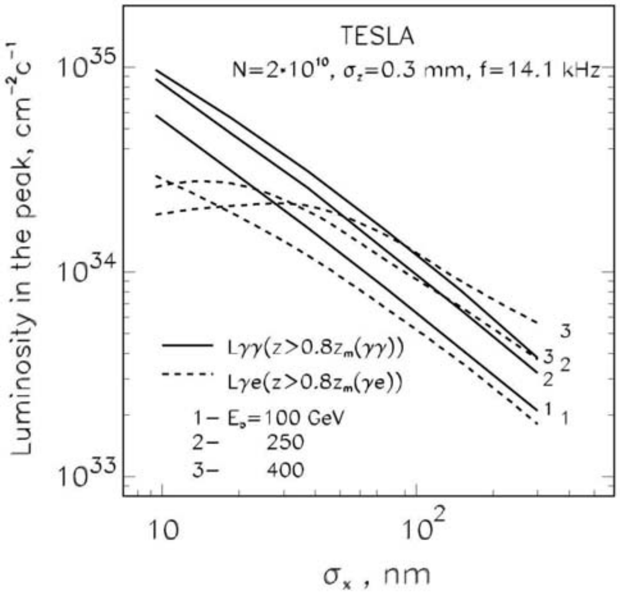
Option:Additional Information

13

Factors limiting γγ,γe luminosities

Collisions effects:

- Coherent pair creation
- Beamstrahlung
- Beam-beam repulsion



On the right: dependence of γγ and γe luminosities in the high energy peak on the horizontal beam size:

For the ~~TESLA~~ ILC electron beams $\sigma_x \sim$ ~~100~~ 300 nm at $2E_0 = 500$. Having beams with smaller emittances one could have by one order higher γγ luminosity.

γe luminosity in the high energy peak is limited due to the beam repulsion and beamstrahlung

At e^+e^- the luminosity is limitted by collision effects (beamstrahlung, instability), while in γγ collsions only by available beam sizes or geometric e^-e^- luminosity (for at $2E_0$<1 TeV).

Photon collider at CLIC

Comparison of ILC and CLIC parameters (important for PLC)

Laser wave length $\lambda \propto E$

for ILC(250-500) λ~1μm, for CLIC(250-3000) λ~ 1 - 4.5 μm

Disruption angle $\theta_d \sim (N/\sigma_z E_{min})^{1/2}$

For CLIC angles θ_d is larger on 20%, not important difference.

Laser flash energy A~10 J for ILC, A~5J for CLIC

Duration of laser pulse τ~1.5 ps for ILC, τ~1.5 ps for CLIC

Pulse structure

ILC Δct~100 m, 3000 bunch/train, 5 Hz (f_{col}~15 kH)

CLIC Δct~0.15 m, ~300 bunch/train, 50 Hz (f_{col}~15 kH)

Laser system ILC – a ring optical cavity with Q>100

CLIC –one pass system

(or short linear cavity?)

Laser system for CLIC

Requirements to a laser system for a photon collider at CLIC

Laser wavelength	~ 1 µm
Flash energy	A~5 J
Number of bunches in one train	354
Length of the train	177 ns=53 m
Distance between bunches	0.5 nc
Repetition rate	50 Hz

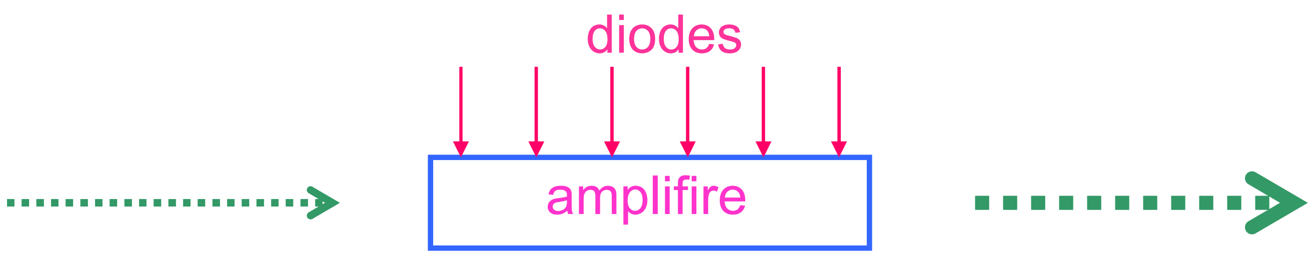
The train is too short for the optical cavity, so one pass laser should be used.

The average power of one laser is 90 kW (two lasers 180 kW).

Solid state lasers pumped by diodes.

One can use solid state lasers pumped by diodes. There are laser media with a storage time of about 1 ms. One laser train contains the energy about 5x534=2000 J. Efficiency of the diode pumping about 20%, therefore the total power of diodes should be P~2*2000/0.001/0.20~20 MW.

LLNL system LIFE based on diode pumping is very close to CLIC requirements and can be reconfigured for CLIC and ILC (talk at HF2012)

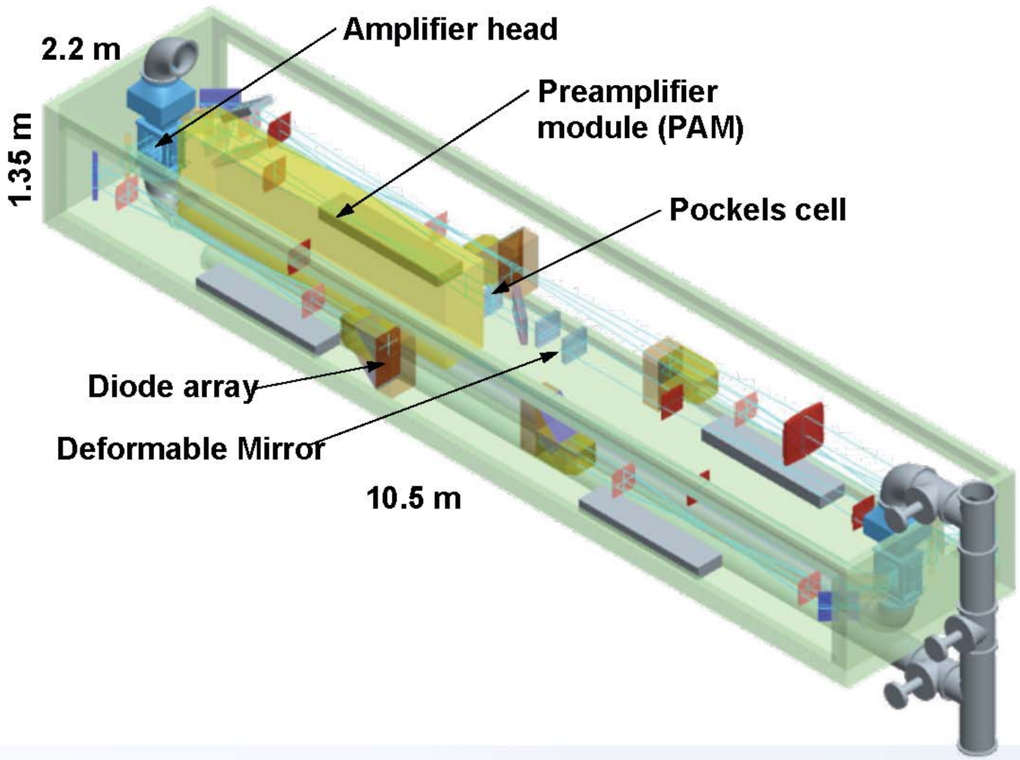


One pass laser system, developed for LIFE (LLNL) is well suited for CLIC photon collider

Project LIFE, LLNL   16 Hz, 8.125 kJ/pulse, 130 kW aver. power

(the pulse can be splited to the CLIC train)

The entire 1ω beamline can be packaged into a box which is 31 m^3 while providing 130 kW average power



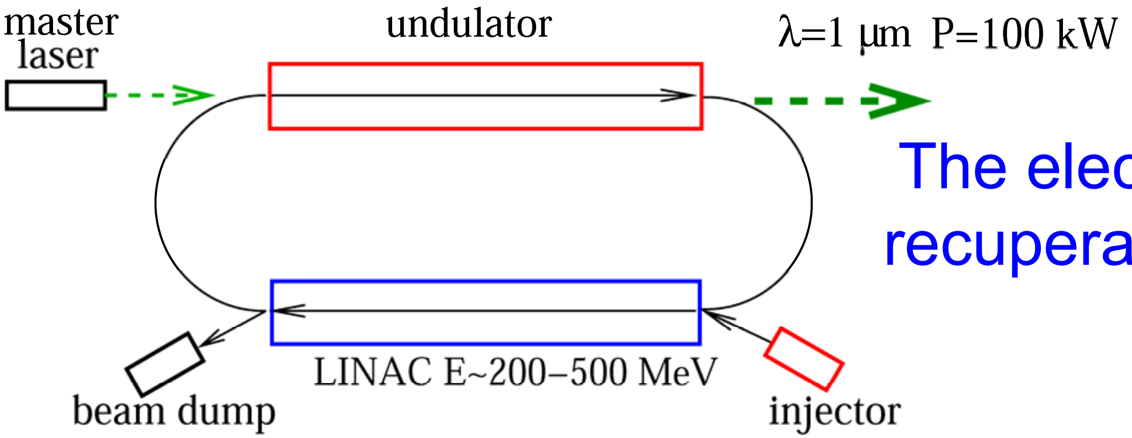
Lawrence Livermore National Laboratory

Option:UCRL#   Option:Additional Information   11   15

May

Another suggestion (V.T,2010):

to use FELs with the energy recuperation instead of diodes for pumping the solid state laser medium.

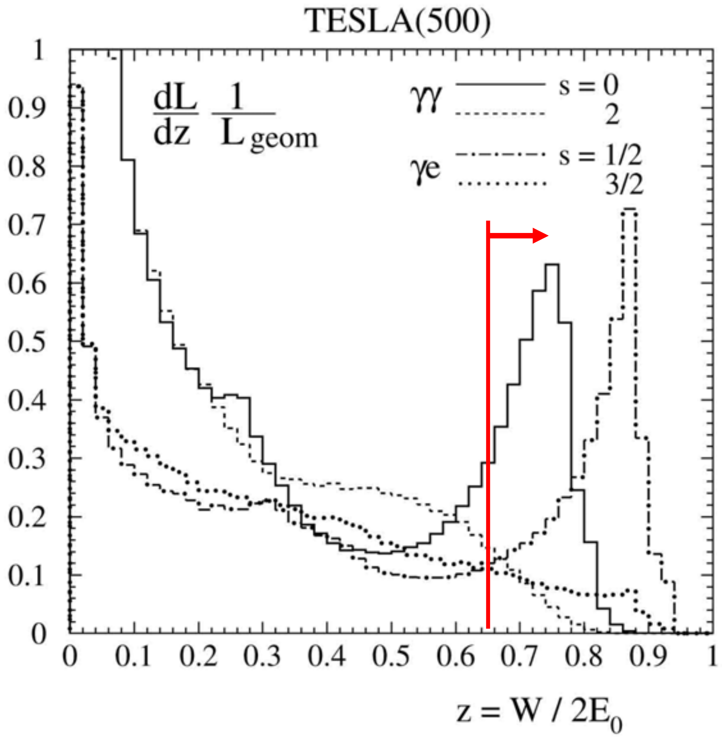


The electron beam energy can be recuperated using SC linac.

With recuperation and 10% wall plug RF efficiency the total power consumption of the electron accelerator from the plug will be about 200 kW/ 0.1 = 2 MW only.

The FEL pumped solid state laser with recuperation of electron beam energy is very attractive approach for short train linear colliders, such as CLIC. Such FEL can be built already now. But diode pumping is simpler and cheaper!

Luminosity



Usually a luminosity at the photon collider is defined as the luminosity in the high energy peak, $z>0.8z_m$.

At energies 2E<1 TeV there no collision effects in γγ collisions and luminosity is just proportional to the geometric e-e- luminosity, which can be, in principle, higher than e+e- luminosity.

$L_{\gamma\gamma}(z>0.8z_m) \sim 0.1 L(e^-e^-, geom)$

(this is not valid for multi-TeV colliders with short beams(CLIC) due to coherent e+e- creation)

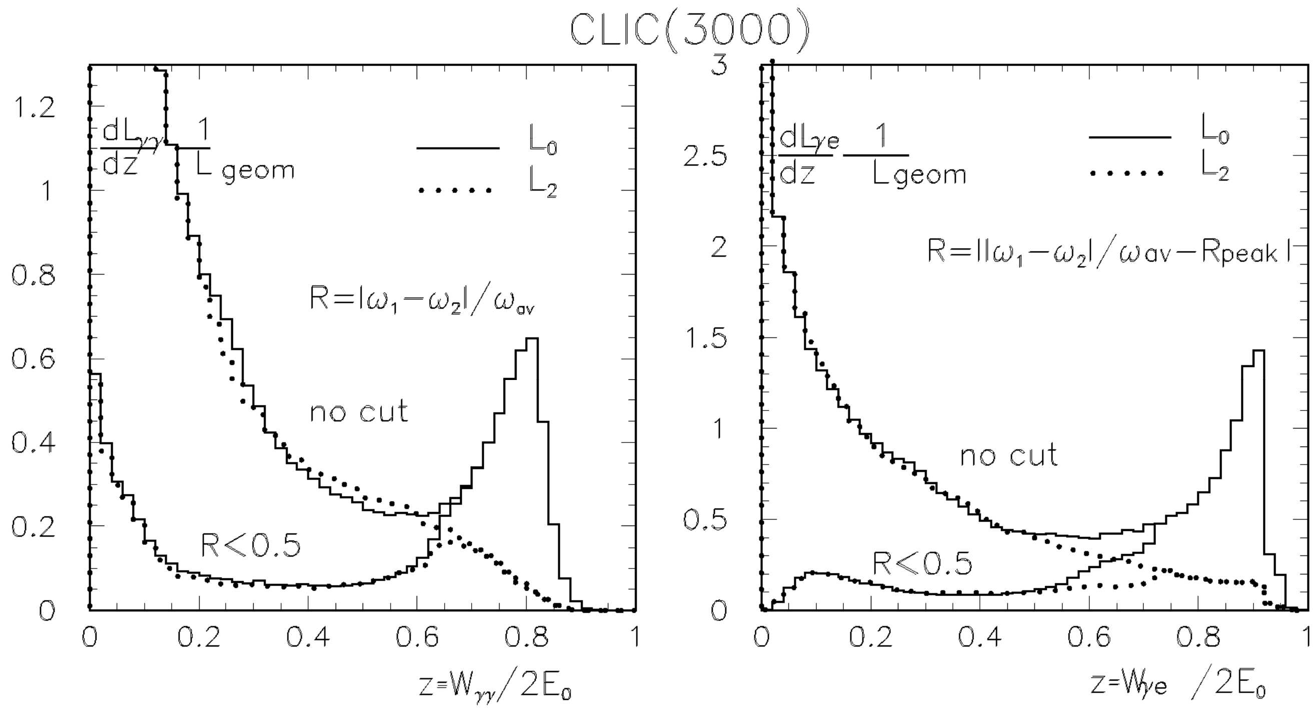
For CLIC(500) $L_{\gamma\gamma}(z>0.8z_m) \sim 3 \cdot 10^{33}$ for beams from DR

For CLIC(500) $L_{\gamma\gamma}(z>0.8z_m) \sim 0.1L(e^-e^-,geom)$

$L_{\gamma\gamma}(z>0.8z_m) \sim 3\cdot10^{33}$ for beams from DR

For CLIC(3000)

Here the $\gamma\gamma$ luminosity is limitted by coherent pair creation (the photon is converted to e+e- pair in the field of the opposing beam). The horizontal beam size can be only 2 times smaller than in e+e- collisions.



V.T.

$L_{\gamma\gamma}(z>0.8z_m) \sim 8\cdot10^{33}$

(may be for not latest parameters)

Photon collider Higgs factory
SAPPHiRE

Submitted to the European Particle Physics Strategy Preparatory Group

SAPPHiRE: a Small $\gamma\gamma$ Higgs Factory

S. A. Bogacz[1], **J. Ellis**[2,3], **L. Lusito**[4], **D. Schulte**[3], **T. Takahashi**[5], **M. Velasco**[4], **M. Zanetti**[6] and **F. Zimmermann**[3]

Aug. 2012

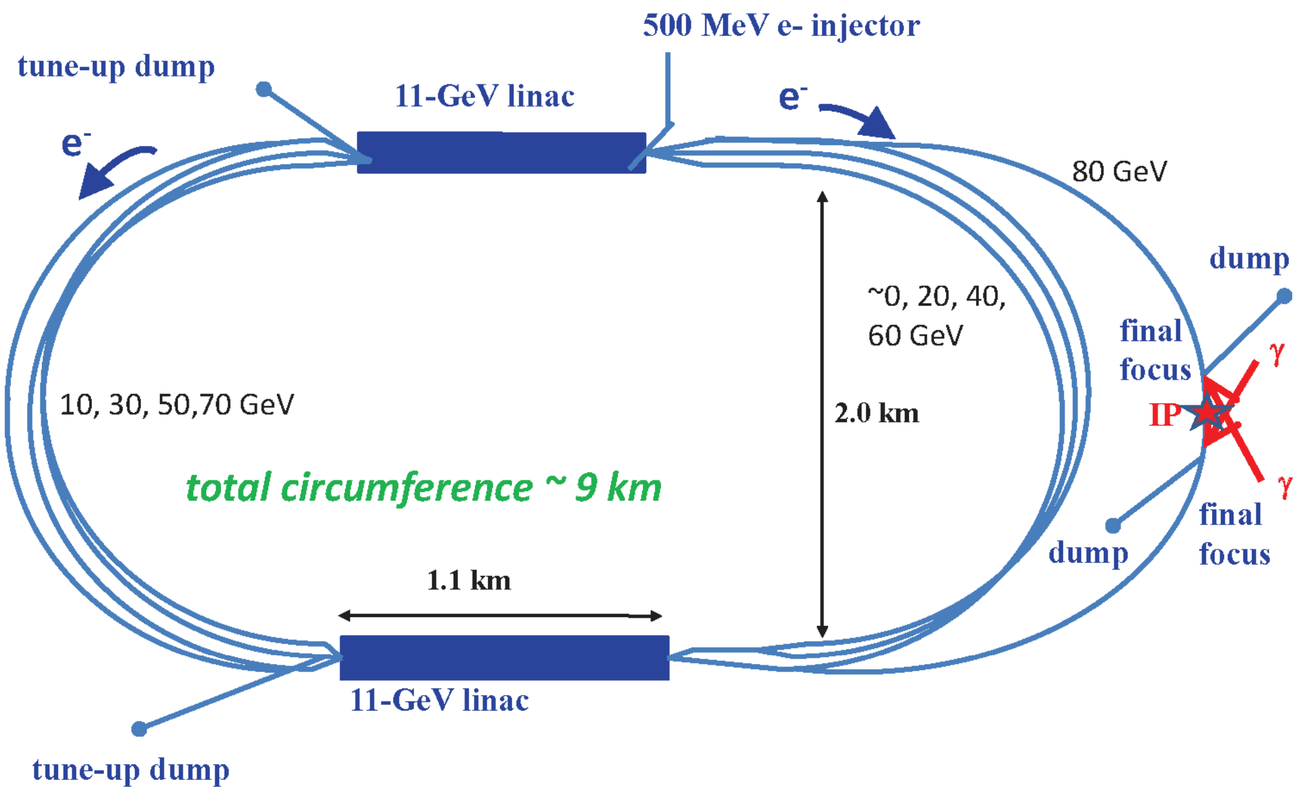


Figure 3: *Sketch of a layout for a $\gamma\gamma$ collider based on recirculating superconducting linacs – the SAPPHiRE concept.*

The scheme is based on LHeC electron ring, but shorter beams (σ_z = 30μm)) and somewhat higher energy, 80 GeV

Table 1: *Example parameters for $\gamma\gamma$ colliders based on CLIC-1 (CLICHE, left column), as optimized for $M_h \sim 115$ GeV [3], and a pair of recirculating superconducting linacs (SAPPHiRE, right column) optimized for $M_h \sim 125$ GeV.*

Variable	Symbol	CLICHE [3]	SAPPHiRE
Total electric power	P	150 MW	100 MW
Beam energy	E	75 GeV	80 GeV
Beam polarization	P_e	0.80	0.80
Bunch population	N	4×10^9	10^{10}
Number of bunches per train	n_b	154	—
Number of trains per rf pulse	n_t	11	—
Repetition rate	f_{rep}	100 Hz	cw
Average bunch frequency	$\langle f_{\text{bunch}} \rangle$	169 kHz	200 kHz
Average beam current	I_{beam}	0.11 mA	0.32 mA
RMS bunch length	σ_z	30 μm	30 μm
Crossing angle	θ_c	$\geq$ 20 mrad	$\geq$ 20 mrad
Normalised horizontal emittance	ϵ_x	1.4 μm	5 μm
Normalised vertical emittance	ϵ_y	0.05 μm	0.5 μm
Nominal horizontal beta function at the IP	β_x^*	2 mm	5 mm
Nominal vertical beta function at the IP	β_y^*	20 μm	0.1 mm
Nominal RMS horizontal IP spot size	σ_x^*	138 nm	400 nm
Nominal RMS vertical IP spot size	σ_y^*	2.6 nm	18 nm
Nominal RMS horizontal CP spot size	$\sigma_x^{C,*}$	154 nm	400 nm
Nominal RMS vertical CP spot size	$\sigma_y^{C,*}$	131 nm	180 nm
e^-e^- geometric luminosity	$\mathcal{L}$	4.8×10^{34} cm^{-2}s^{-1}	2.2×10^{34} cm^{-2}s^{-1}

200 kHz!!!

Table 2: *Example parameters for the CLICHE mercury laser system [3], and for the SAPPHiRE laser system, assuming $\mathcal{L}_{ee} = 4.8 \times 10^{34}$ cm^{-2}s^{-1} and $\mathcal{L}_{ee} = 2.2 \times 10^{34}$ cm^{-2}s^{-1}, respectively.*

Variable	Symbol	CLICHE [3]	SAPPHiRE
Laser beam parameters			
Wavelength	λ_L	0.351 μm	0.351 μm
Photon energy	$\hbar\omega_L$	3.53 eV = 5.65×10^{-19} J	3.53 eV
Number of laser pulses per second	N_L	169400 s^{-1}	200000 s^{-1}
Laser peak power	W_L	2.96×10^{22} W/m^2	6.3×10^{21} W/m^2
Laser peak photon density		5.24×10^{40} photons/m^2/s	1.1×10^{40} photons/m^2/s
Photon beam			
Number of photons per electron bunch	N_γ	9.6×10^9	1.2×10^{10}
$\gamma\gamma$ luminosity for $E_{\gamma\gamma} \geq 0.6 E_{CM}$	$\mathcal{L}_{\gamma\gamma}^{peak}$	3.6×10^{33} cm^{-2}s^{-1}	3.6×10^{33} cm^{-2}s^{-1}

!

Many 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. That would be great for any PLC!
3. Conservation of polarization in rings is a problem (due to the energy spread, too many spin rotation).
4. The bunch length (σ_z = 30 μm) is very close to condition of coherent radiation in arcs.
5. The length of the ring 9 km (2.2 km linac, 30 km arcs). The warm LC with G=50 MeV/m would have L~4 km total length (with the final focus) and can work with smaller emittances and thus can have a higher luminosity. Where is profit?

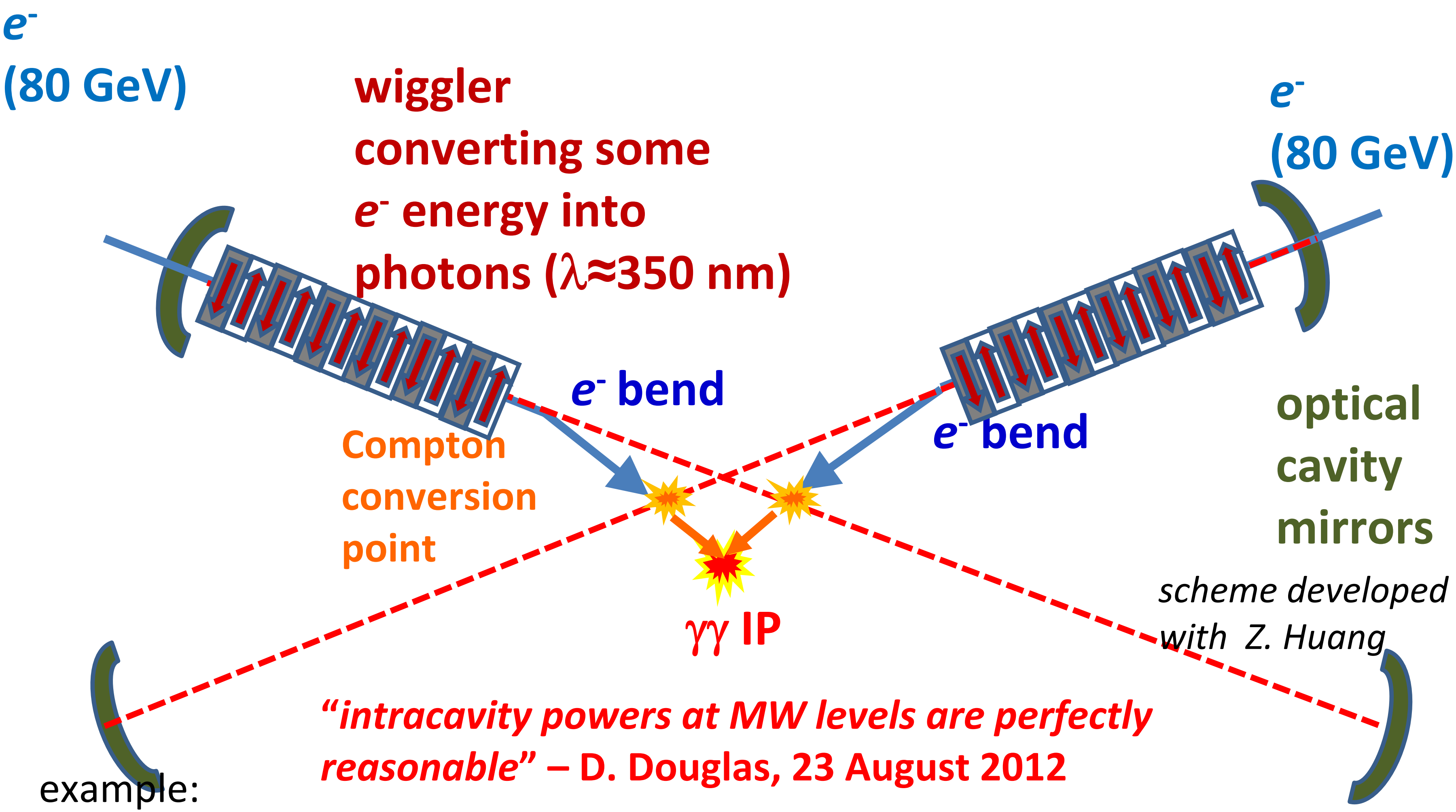
6. The PLC with E=80 GeV and λ=1.06/3 μm have very low energy final electrons with energies down to E=2 GeV. This courses very large disruption angles in the field of opposing beam and due to deflection in the solenoid field (due to crab crossing). Namely due to this reason TESLA (ILC) always considered the Higgs factory with E>100 GeV and λ=1.06 μm. E>100 GeV is not possible at Sapphire due to unacceptable emittance dilution and energy spread. Ring colliders (Sapphire) have no possibility for increasing energy.

7. The repetition rate 200000 is very uncomfortable for laser system, optical cavity can help, but it is much more demanded than for ILC.

8. 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).

option: self-generated FEL γ beams (instead of laser)?

(I do not believe, there is no space near IP!)



***"intracavity powers at MW levels are perfectly reasonable"* – D. Douglas, 23 August 2012**

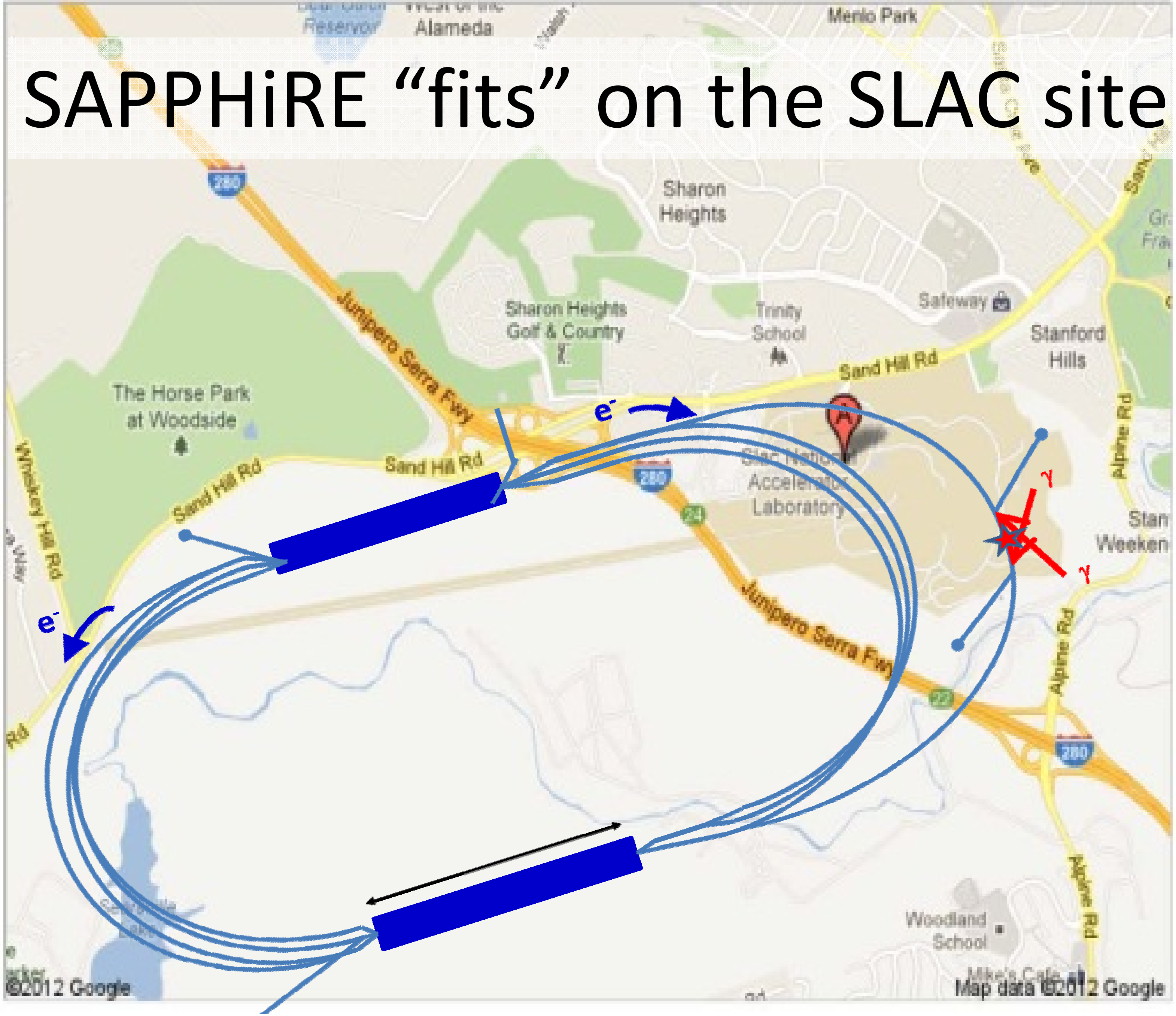
example:

λ_u=200 cm, B=0.625 T, L_u=100 m, $U_{0,SR}$=0.16 GeV, 0.1%P_{beam}≈25 kW

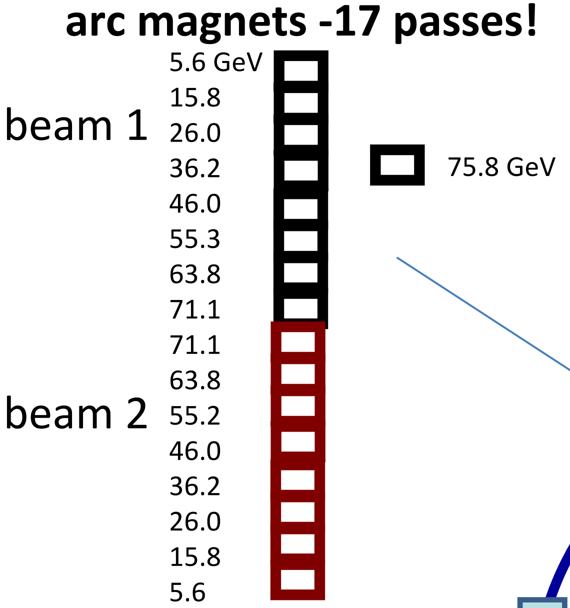
Sapphire has stimulated many other proposals of ring gamma-gamma Higgs factories:

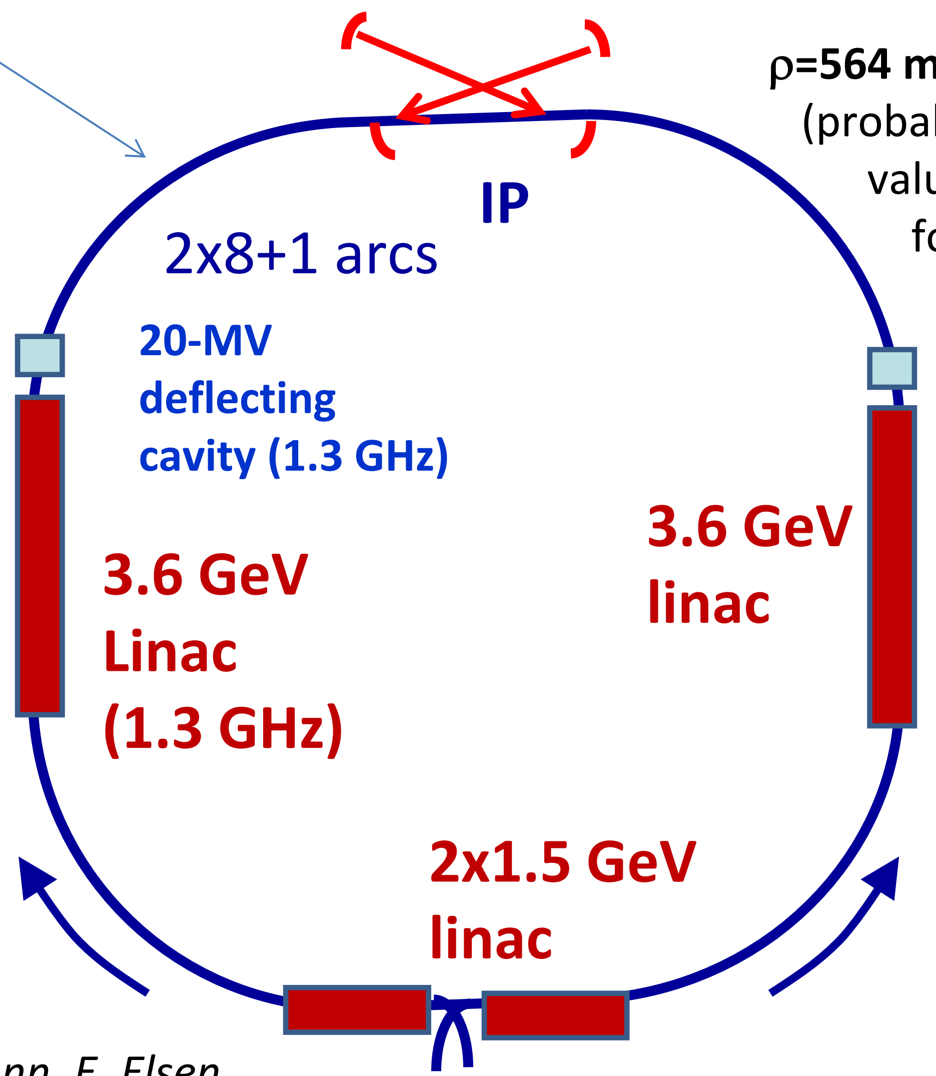
from F.Zimmermann talks

SAPPHiRE "fits" on the SLAC site



HERA Tunnel Filler





ρ=**564 m** for arc dipoles (probably pessimistic; value assumed in the following)

real-estate linac Gradient ~ 10 MV/m

total SC RF = 10.2 GV

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

Edward Nissen

Town Hall meeting Dec 19 2011

Possible Configurations at JLAB

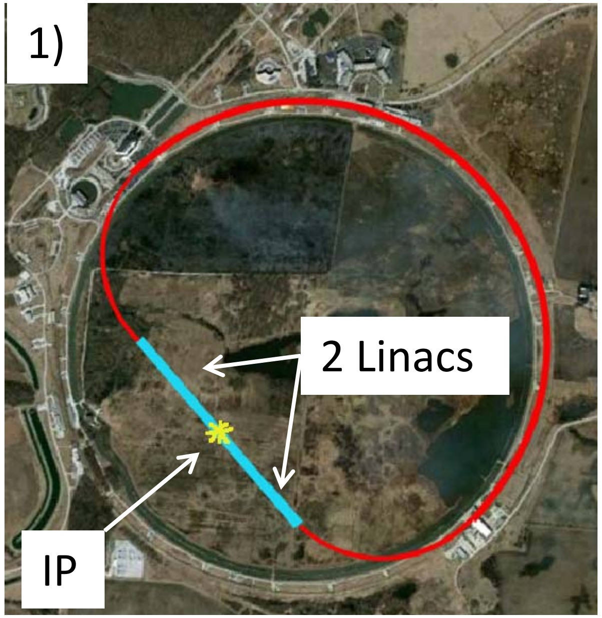
85 GeV Electron energy
γ c.o.m. 141 GeV

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

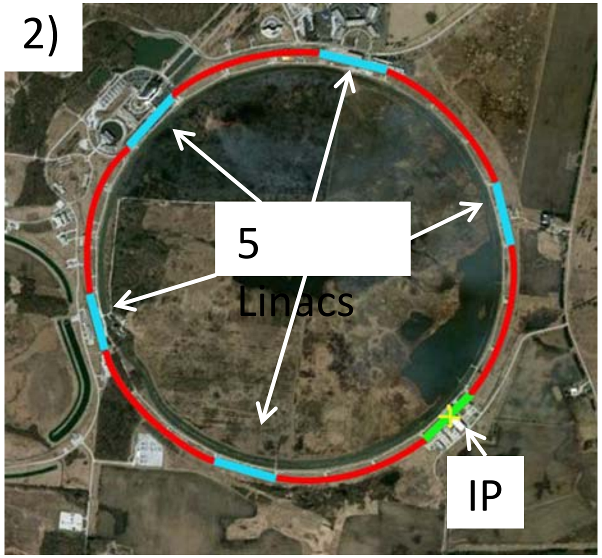
Edward Nissen

Possible Configurations at FNAL

Tevatron Tunnel Filler Options



Top Energy	80 GeV	80 GeV
Turns	4	5
Avg. Mag. ρ	661.9 m	701.1 m
Linacs (2)	10.68GeV	8.64GeV
δp/p	8.84×10^{-4}	8.95×10^{-4}
ϵ_{nx} Growth	2.8μm	2.85μm



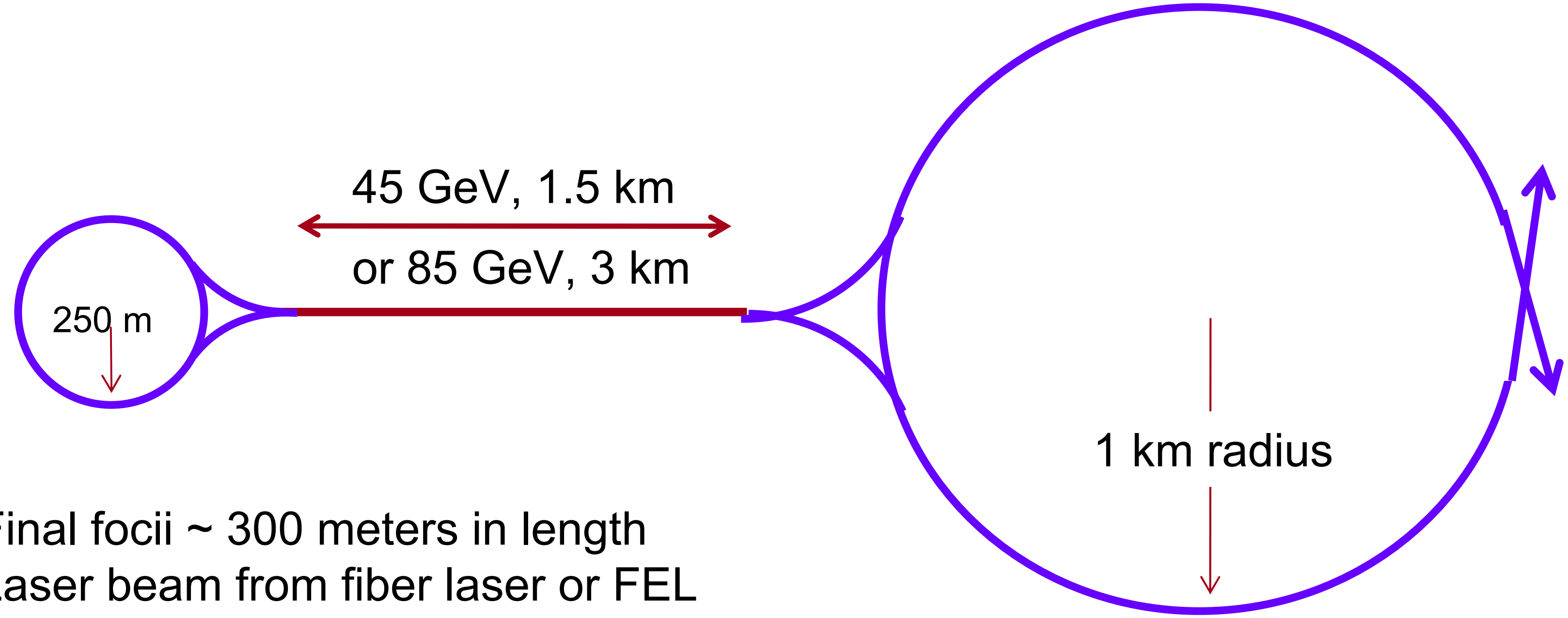
Top Energy	80 GeV	80 GeV
Turns	3	4
Magnet ρ	644.75 m	706.65 m
Linacs (5)	5.59GeV	4.23GeV
δp/p	6.99×10^{-4}	7.2×10^{-4}
ϵ_{nx} Growth	1.7μm	1.8μm

- Both versions assume an effective accelerating gradient of 23.5 MeV/m
- Option 1: would require more civil construction, but would only require two sets of spreader /recombiner magnets, and only two linacs, for greater simplicity.
- Option 2: would require 10 sets of spreader /recombiner magnets and 5 linacs but would achieve better beam parameters

SLC-ILC-Style (SILC) Higgs Factor

(T. Raubenheimer)

- Some challenges with 2-pass design!



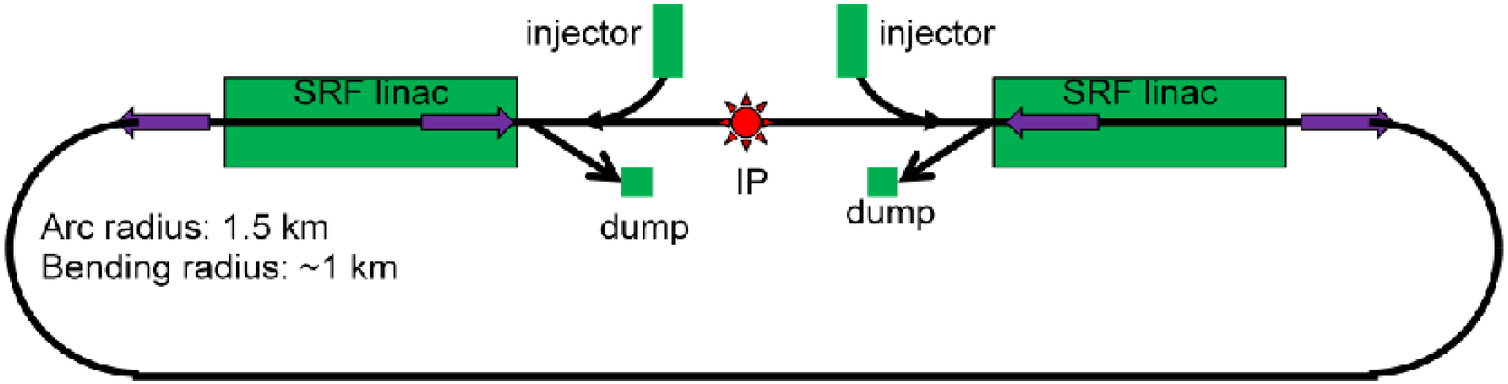
Final focii ~ 300 meters in length
Laser beam from fiber laser or FEL
2 x 85 GeV is sufficient for $\gamma\gamma$ collider
Upgrade with plasma afterburners to reach 2 x 120 GeV. Then final ring should have R=3.5 km (to preserve emittance).

Jefferson Lab Technote JLAB-TN-12-053 October 31,2012

Design Concept of A γ-γ Collider-Based Higgs Factory Driven by a Thin Laser Target and Energy Recovery Linacs

Yuhong Zhang

Thomas Jefferson National Accelerator Facility
12000 Jefferson Avenue, Newport News, VA 23607 USA



Main idea: smaller conversion coefficient e→γ, but higher beam current due to recuperation of unscattered electrons energy.

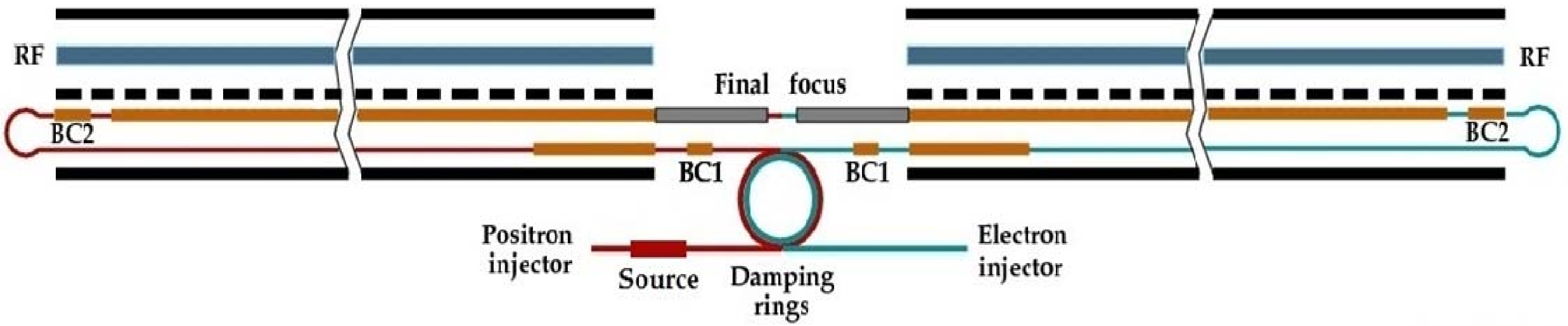
It does not work:

a) electrons experience strong beamstrahlung and are not suited for recuperation due to the energy spread,

b) there is no improvement of luminosity, only decrease, because emittance increases with the increase of N. Maximum L for k~1.

KEK the X-band linear collider Higgs factory (e+e-, γγ, γe) 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

Serkant Ali CETİN
Doğuş University, Istanbul, Turkey

Evangelos N. GAZIS
National Technical University, Athens, Greece

Bora ISILDAK
OÅNzyeğin University, İstanbul, Turkey

Fatih OÅNmer İLDAY
Bilkent University, Ankara, Turkey

onstantinos KORDAS and Chariclia PETRIDOU
Aristotle University of Thessaloniki, Thessaloniki, Greece

Yannis K. SEMERTZIDIS
Brookhaven National Laboratory, New York, USA

Saleh SULTANSOY
TOBB Economy & Technolgy University, Ankara, Turkey and
ANAS, Institute of Physics, Baku, Azerbaijan

GoÅNkhan UÅNNEL
University of California at Irvine, Irvine, USA

Konstantin ZIOUTAS
University of Patras, Patras, Greece

ACCELERATOR

An electron linac with two arcs bending in opposite directic

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)

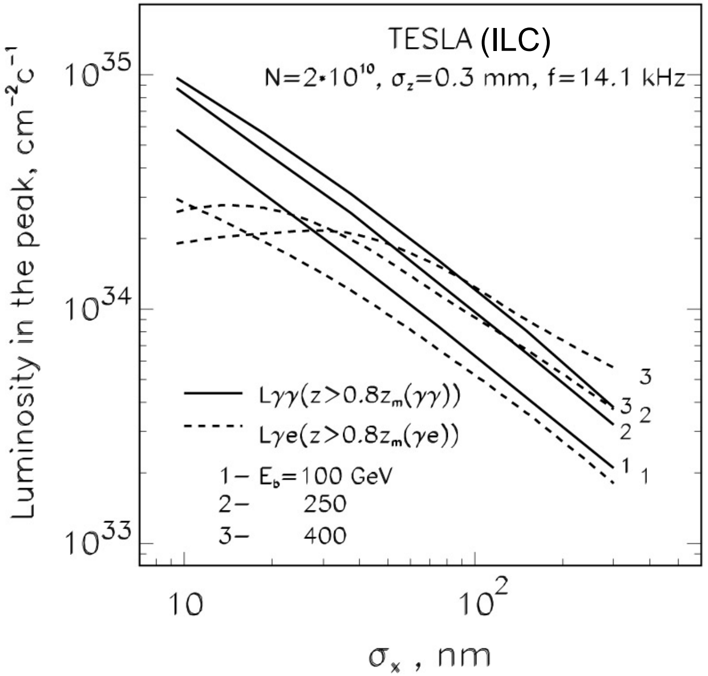
L=1.6 km !

My dreams of $\gamma\gamma$ factories

(based on ILC, with very low emittances, without damping rings)

Factors limiting $\gamma\gamma$,γe luminosities

Telnov,1998



Collision effects:

- •Coherent pair creation ($\gamma\gamma$)
- •Beamstrahlung (γe)
- •Beam-beam repulsion (γe)

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

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

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

Method based on longitudinal emittances

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, $E_{min} \sim 75$ 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!

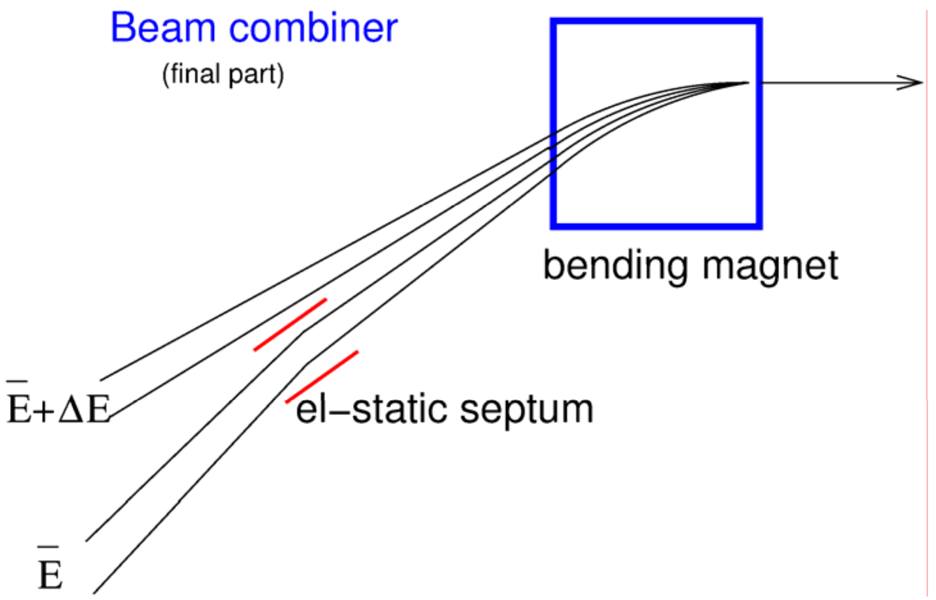
So, photoguns have much smaller longitudinal emittances than it is needed for linear collider (both e+e- or $\gamma\gamma$).

How can we use this fact?

A proposed method

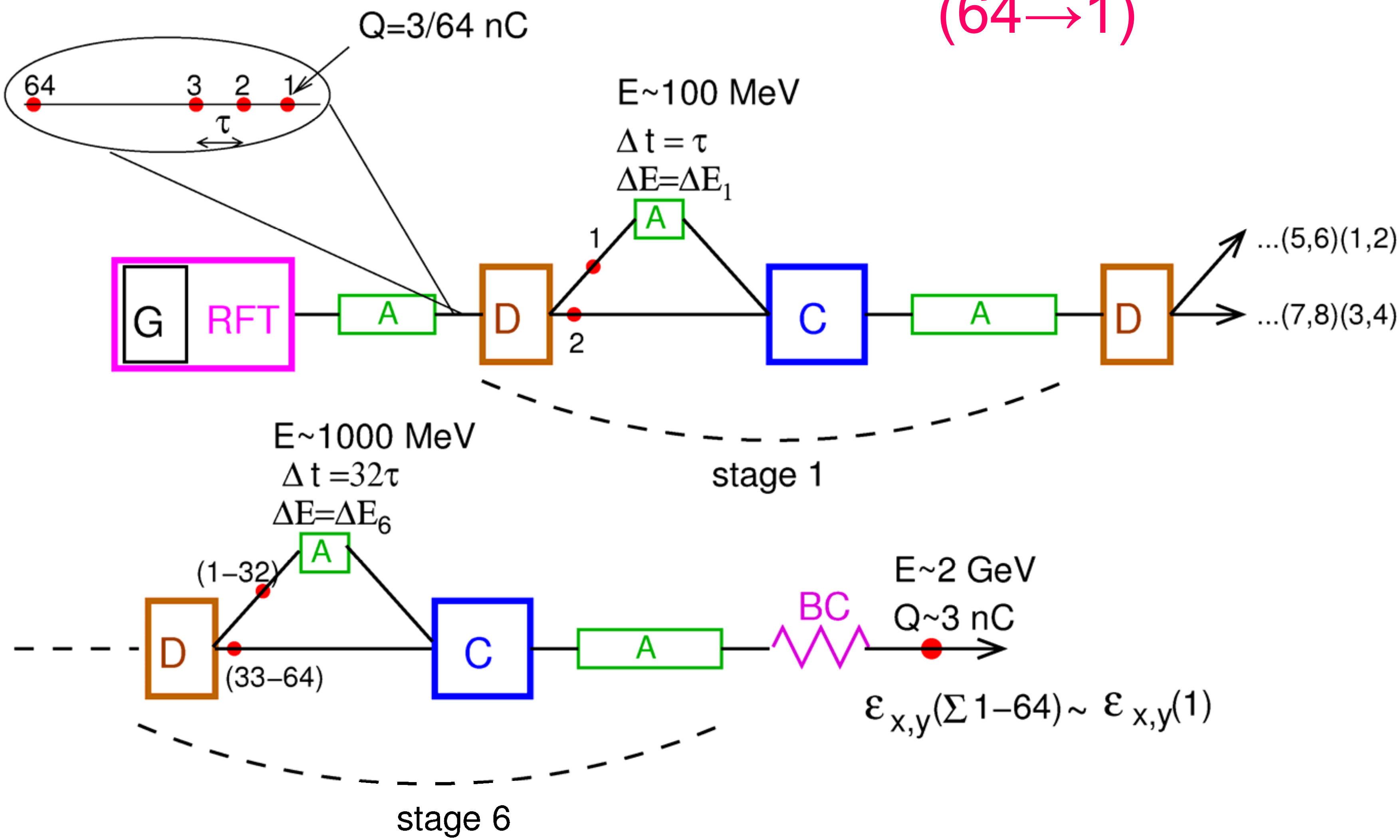
Let us combine many low charge, low emittance beams from photo-guns to one bunch using some differences in their energies. The longitudinal emittance increases approximately proportionally to the number of combined bunches while the transverse emittance (which is most important) remains almost constant.

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)



G –photogun, A –RF–cavities (accel), RFT –round to flat transformer,

D –deflector, C –beam combiner, BC –bunch compressor

Hopes

Beam parameters: $N=2\cdot 10^{10}$ (Q~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) $\varepsilon_{nx}\sim 10^{-4}$ cm, $\varepsilon_{ny}=10^{-6}$ cm, $\beta_x=0.1$ cm, $\beta_y=0.04$ cm,

The ratio of geometric luminosities

$$L_{RFgun}/L_{DR}=\sim 10$$

So, with polarized RF-guns one can get the luminosity ~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, the next step is the design and construction of the laser system prototype. Now, due to LIFE project it seems that one pass scheme becomes very attractive.
- PLC at CLIC is more difficult due to much shorter trains. However LIFE help here as well.
- PLC SAPPHIRE proposal is does not look realistic due to technical problems, restriction on energy and absence of e+e- collisions.

  All PLC for Higgs without e+e- has not sufficient physics case.
- PLC without damping rings is possible, could have even higher (or much higher) luminosity, needs further study. That could open the way to γγ factories, to precision measurement of the Higgs self coupling etc (if there is any new physics in the sub-TeV region).

Conclusion (contin.)

- The ILC is close to approval (in Japan). It is very important to make the final ILC design compatible with the photon collider (as was required by the ILC scope document many years ago)