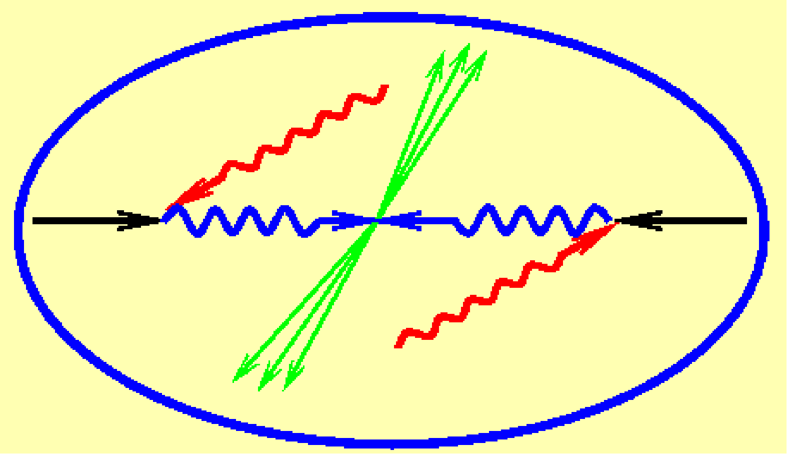


Photon collider Higgs Factories

Valery Telnov

Budker INP, Novosibirsk

LC-ECFA-2013, DESY, May 28

The discovery of the Higgs boson have triggered appearance of many proposals of Higgs factories for precision measurement of the Higgs properties.

Among them are photon colliders (~ 10 projects) without e+e- (in addition to PLC based on e+e- linear colliders ILC, CLIC, etc?)

Below is a brief review of these proposals.

Higgs Factories Dreams

Higgs factory colliders

HF2012,
FNAL, Nov.2012

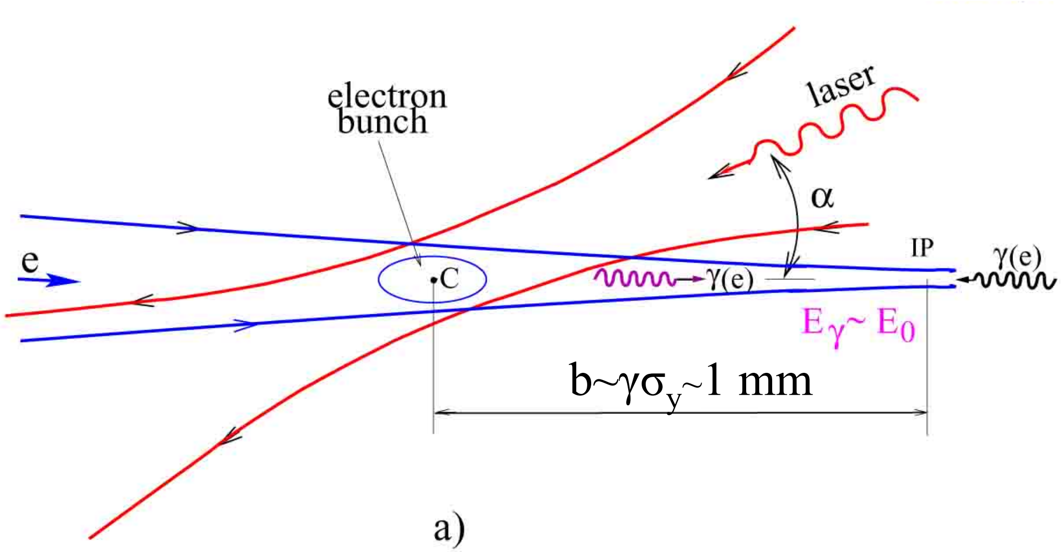
- Linear e+e- collider:
  - ILC
  - CLIC
  - X-band klystron based
- Circular e+e- collider:
  - LEP3
  - TLEP
  - SuperTRISTAN
  - Fermilab site-filler
  - China Higgs Factory (CHF)
  - SLAC/LBNL big ring
- Muon collider
  - Low luminosity, High luminosity
- $\gamma\gamma$ collider:
  - ILC-based
  - CLIC-based
  - Recircul. linac-based SAPPHiRE + HERA,Tevatron rings
  - SLC-type
  - etc

Contents

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

Scheme of $\gamma\gamma$, γe collider

GKST 1981

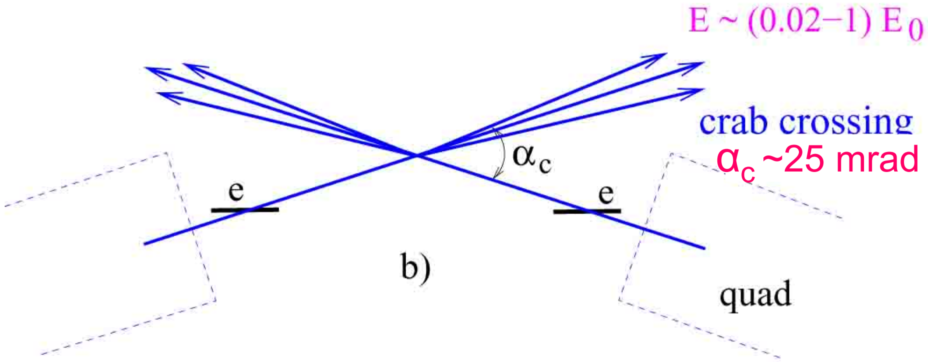


a)

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

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

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



b)

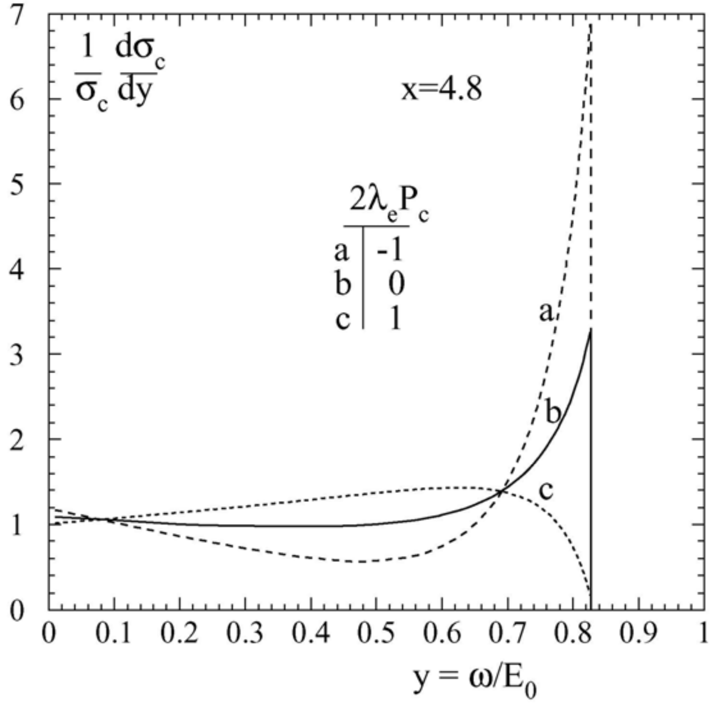
$x = 4.8$ is the threshold for
$\gamma\gamma_L \to e^+e^-$ at conv. reg.

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

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

Electron to Photon Conversion

Spectrum of the Compton scattered photons

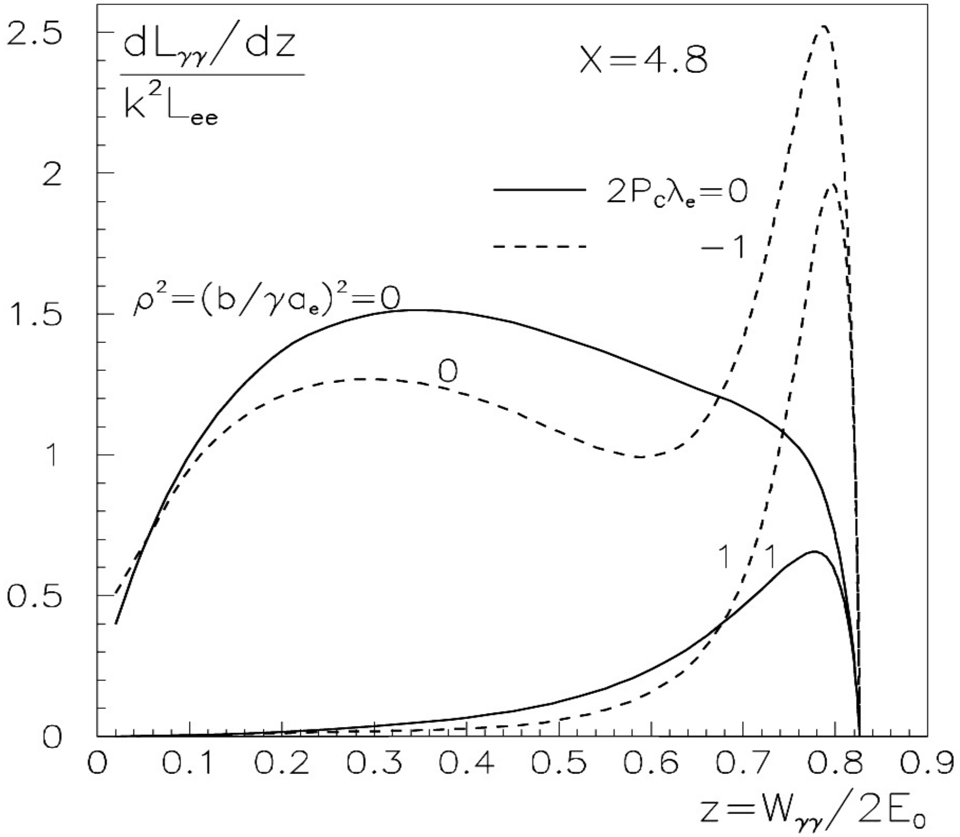


λ_e – electron longitudinal polarization
P_c – helicity of laser photons, $x \approx \frac{4E_0\omega_0}{m^2c^4}$

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

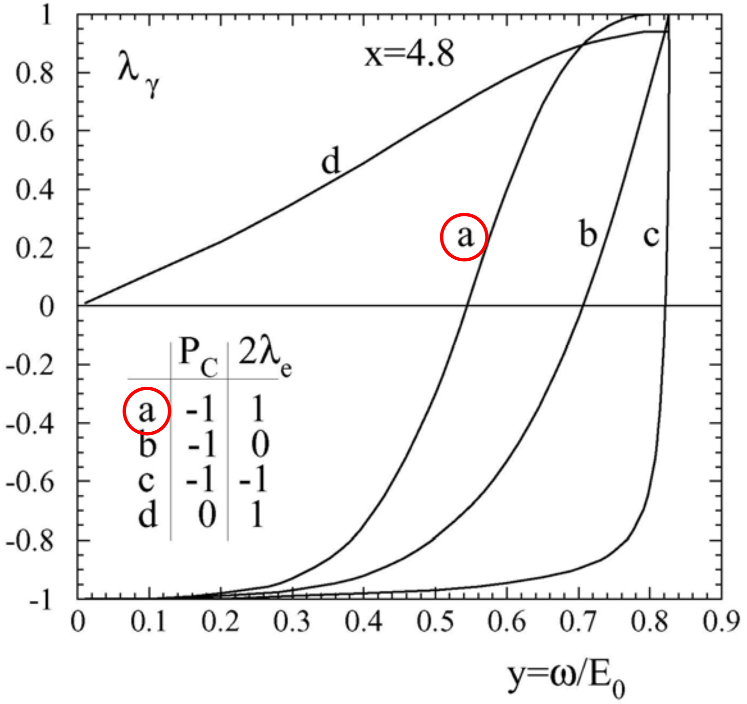
Ideal luminosity distributions, monohromatization

(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 $\lambda_\gamma \approx 1$)

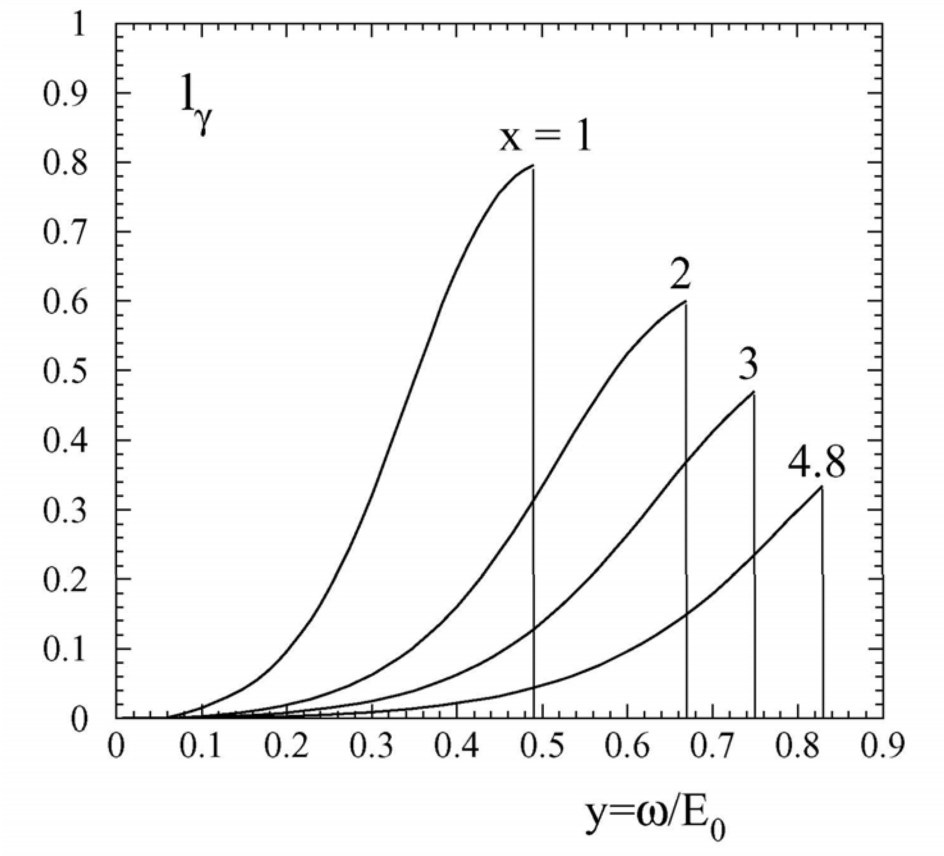
The cross section of the Higgs production

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

The cross section for main backgound

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

Linear polarization of photons



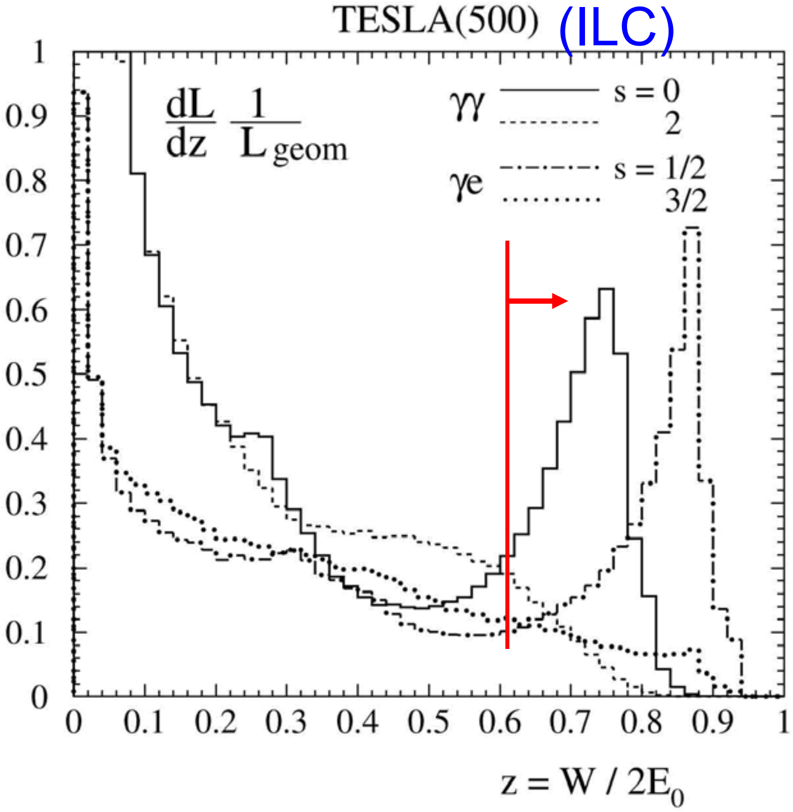
$\sigma \propto 1 \pm l_{\gamma 1} l_{\gamma 2} \cos 2\varphi$ ± for CP=±1

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

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

(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.

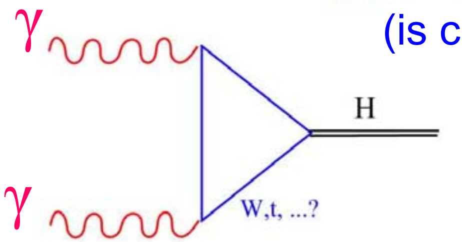
At present only light Higgs boson is discover.

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

Some examples of physics at PLC

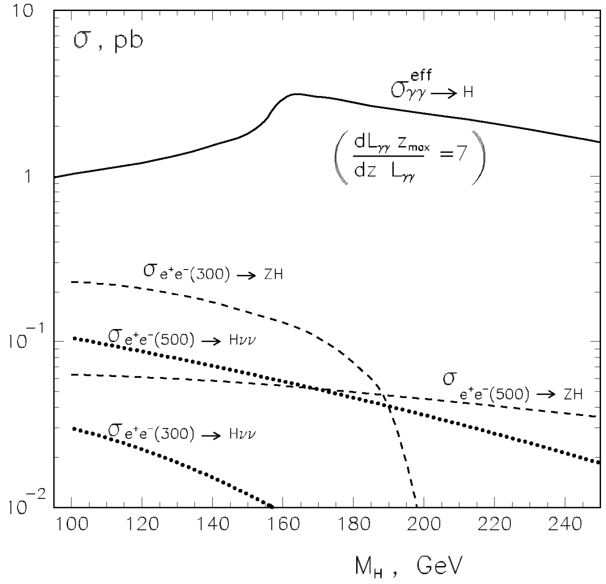
Higgs boson

(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

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

At ILC

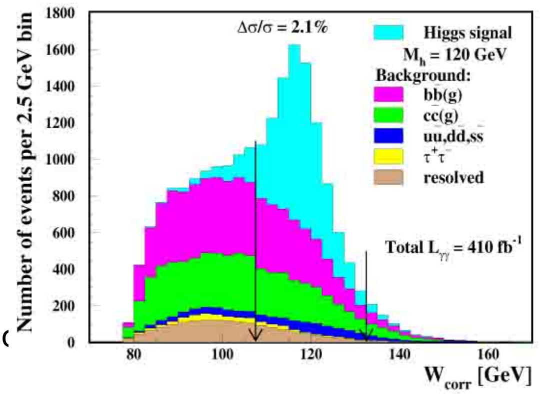
$$\frac{N(\gamma\gamma\to H)}{N(e^+e^-\to H+X)}\sim 1-10$$

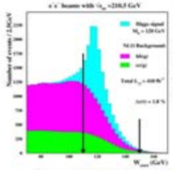
For M_H=115-250 GeV

H→bb

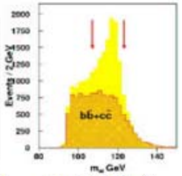
realistic simulation P.Niezurawski et al

(previc

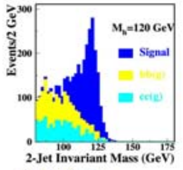




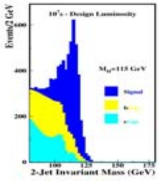
Niezurawski(TESLA)



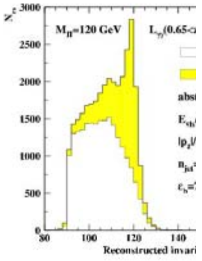
Rosca(TESLA)



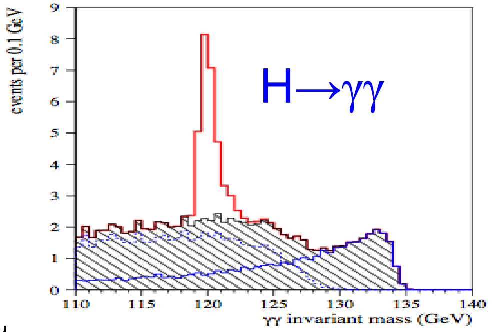
Asner(NLC)



Asner(Cliche)



S.Soldner-Rembold
(thr first simulation)



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

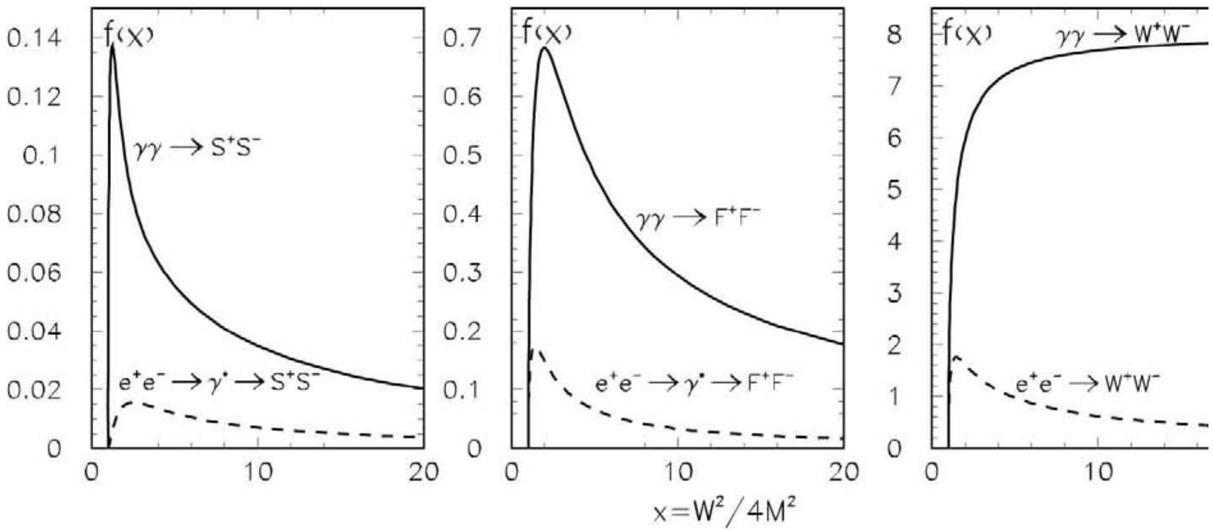
Charged pair production in e^+e^- and $\gamma\gamma$ collisions.

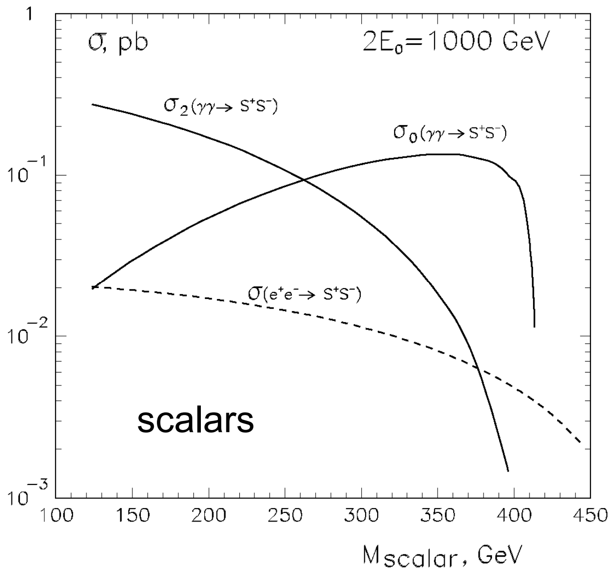
unpolarized beams

(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:

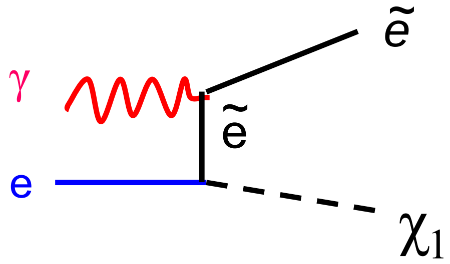
in e^+e^- collisions $M_{H,A}^{max} \sim E_0$ ($e^+e^- \to H + A$)
in $\gamma\gamma$ collisions $M_{H,A}^{max} \sim 1.6E_0$ ($\gamma\gamma \to H(A)$)

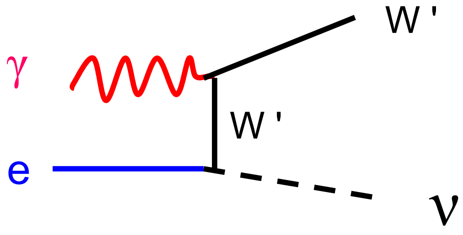
For some SUSY parameters H,A can be seen only in $\gamma\gamma$
(but not in e+e- and LHC)

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 ± signs correspond to CP$= \pm 1$ scalar particles.

Measurement of CP violating asymmetry

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

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

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

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, ττ, μμ, 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.

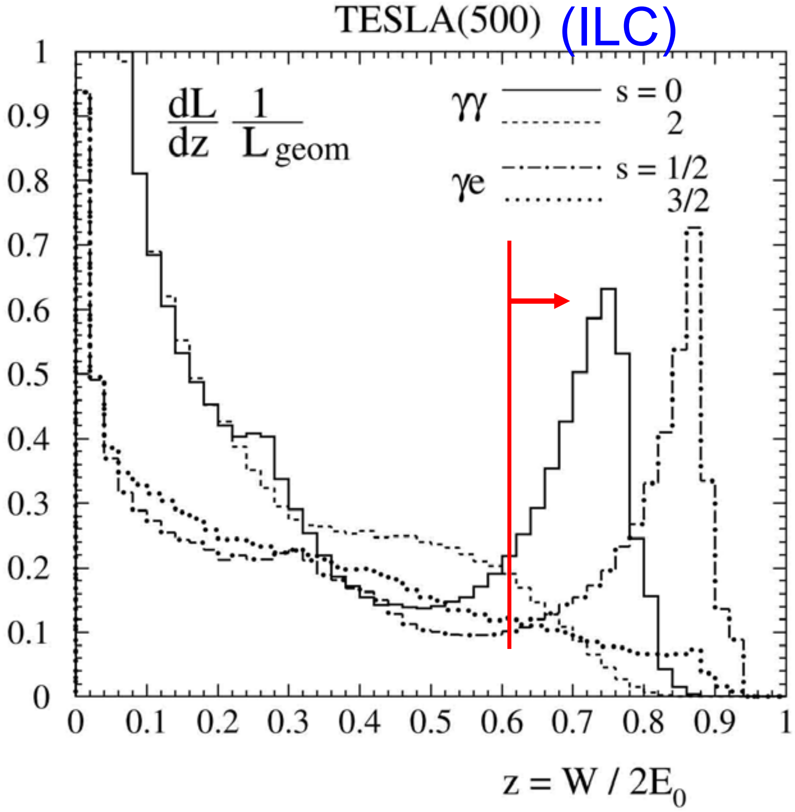
The laser scheme (optical cavity) was considered by experts, there is no stoppers. Required laser technique is developed independently for many other applications based on Compton scattering. Recently LLNL started work on LIFE lasers for thermonuclear plant which seems very attractive (one pass laser).

Further developments need political decisions and finances.

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

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

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

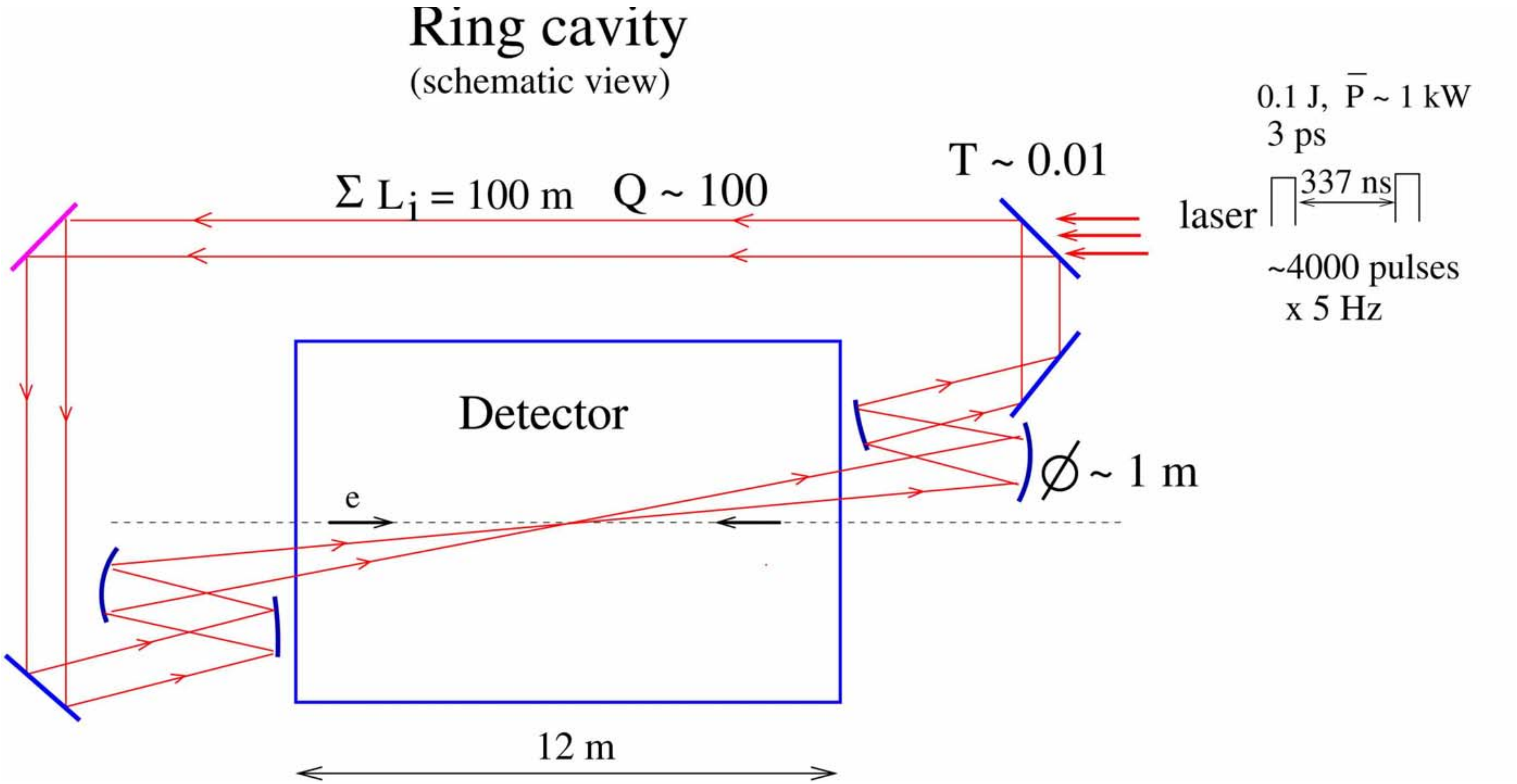
Requirements for laser

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

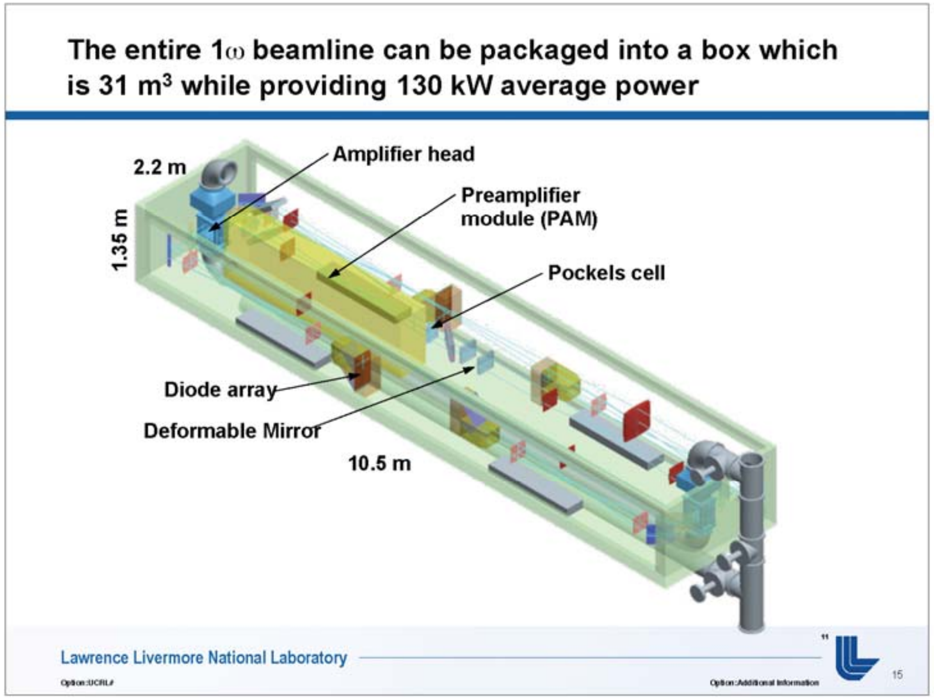


The cavity includes adaptive mirrors and diagnostics. Optimum angular divergence of the laser beam is ±30 mrad, A≈9 J (k=1), $\sigma_t \approx 1.3$ ps, $\sigma_{x,L}$~7 μm

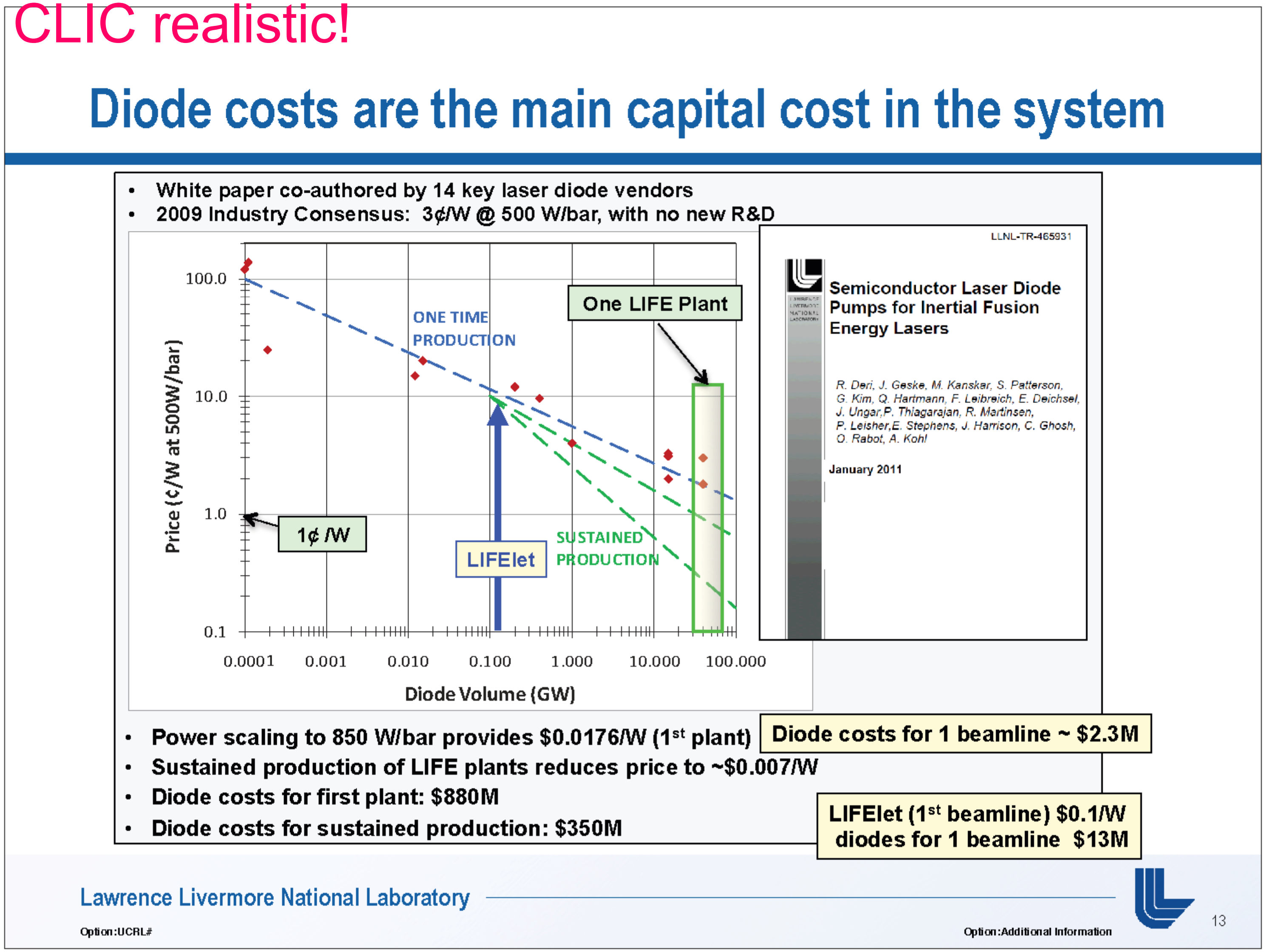
Recently new option has appeared, one pass laser system, based on new laser ignition thermonuclear facility

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

(the pulse can be split into the ILC train)


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

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

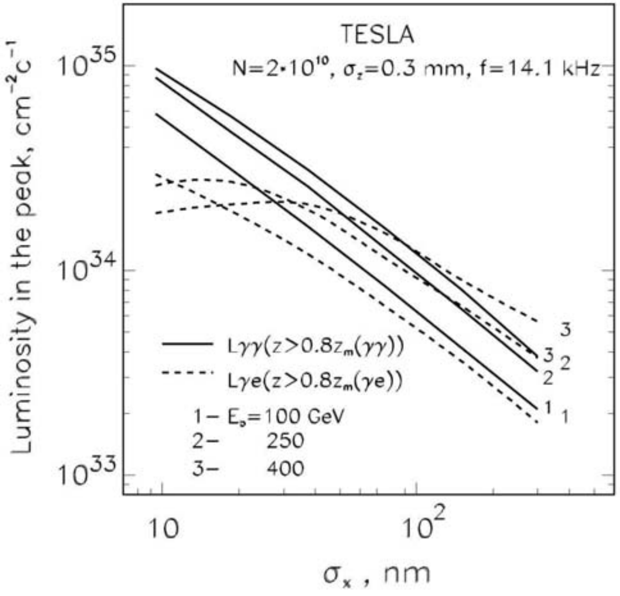
13

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) $\lambda \sim 1 \mu m$, for CLIC(250-3000) $\lambda \sim 1 - 4.5 \mu m$

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 $\tau \sim 1.5$ ps for ILC, $\tau \sim 1.5$ ps for CLIC

Pulse structure

ILC $\Delta ct \sim 100$ m, 3000 bunch/train, 5 Hz ($f_{col} \sim 15$ kH)

CLIC $\Delta ct \sim 0.15$ m, ~300 bunch/train, 50 Hz ($f_{col} \sim 15$ 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

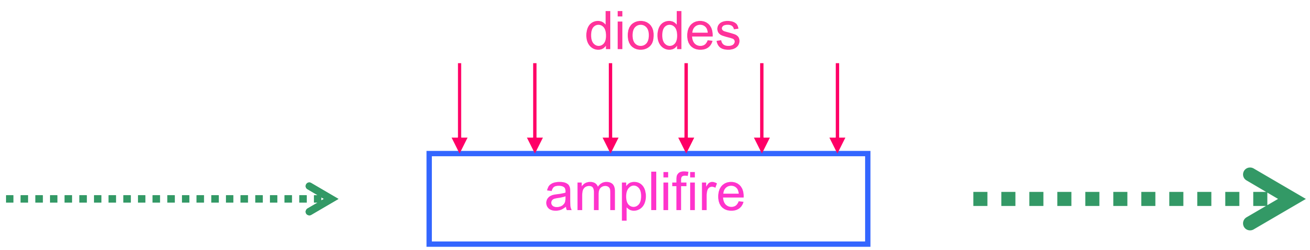
The train is too short for the optical cavity, so one pass laser should be used.

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.

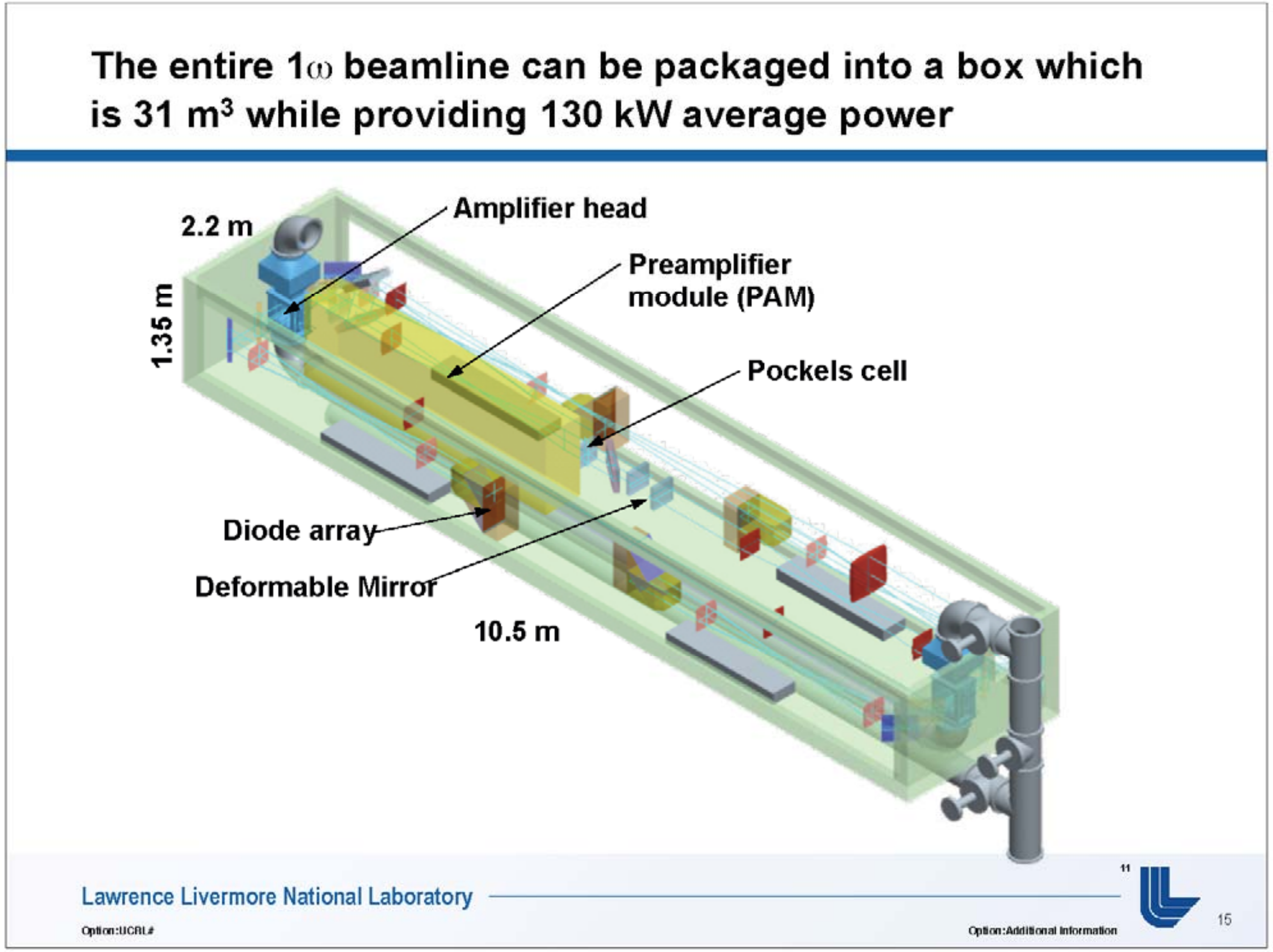
LLNL system LIFE based on diode pumping is very close to CLIC requirements and can be reconfigured for CLIC and ILC (talk at HF2012)



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

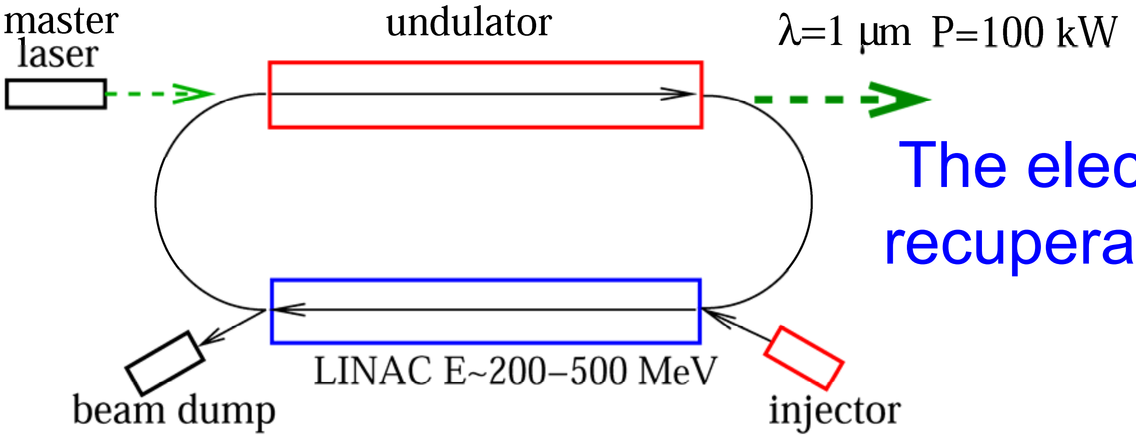
(the pulse can be split into the CLIC train)



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

Another suggestion (V.T,2010):

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

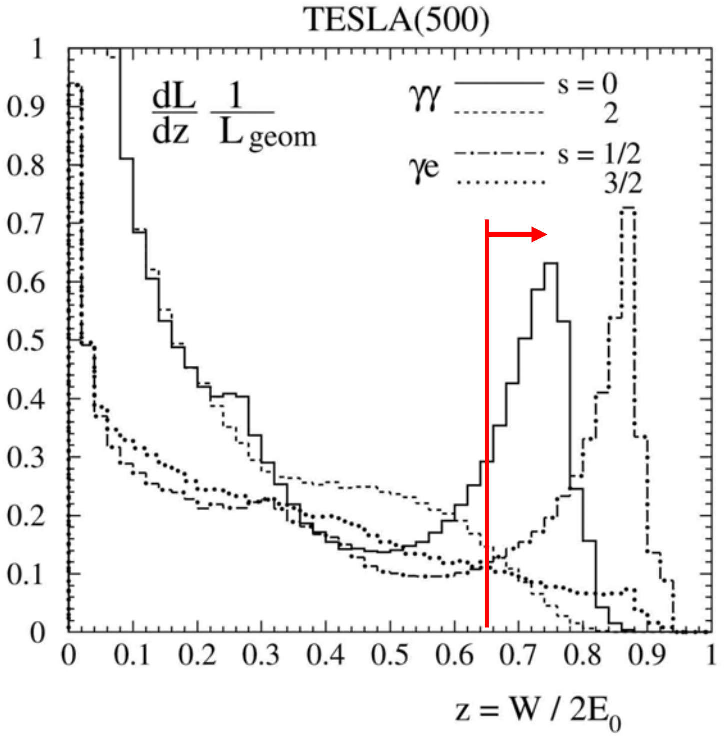


The electron beam energy can be recuperated using SC linac.

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.

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

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

For CLIC(500) $L_{\gamma\gamma}(z>0.8z_m) \sim 3\cdot10^{33}$ for beams from DR

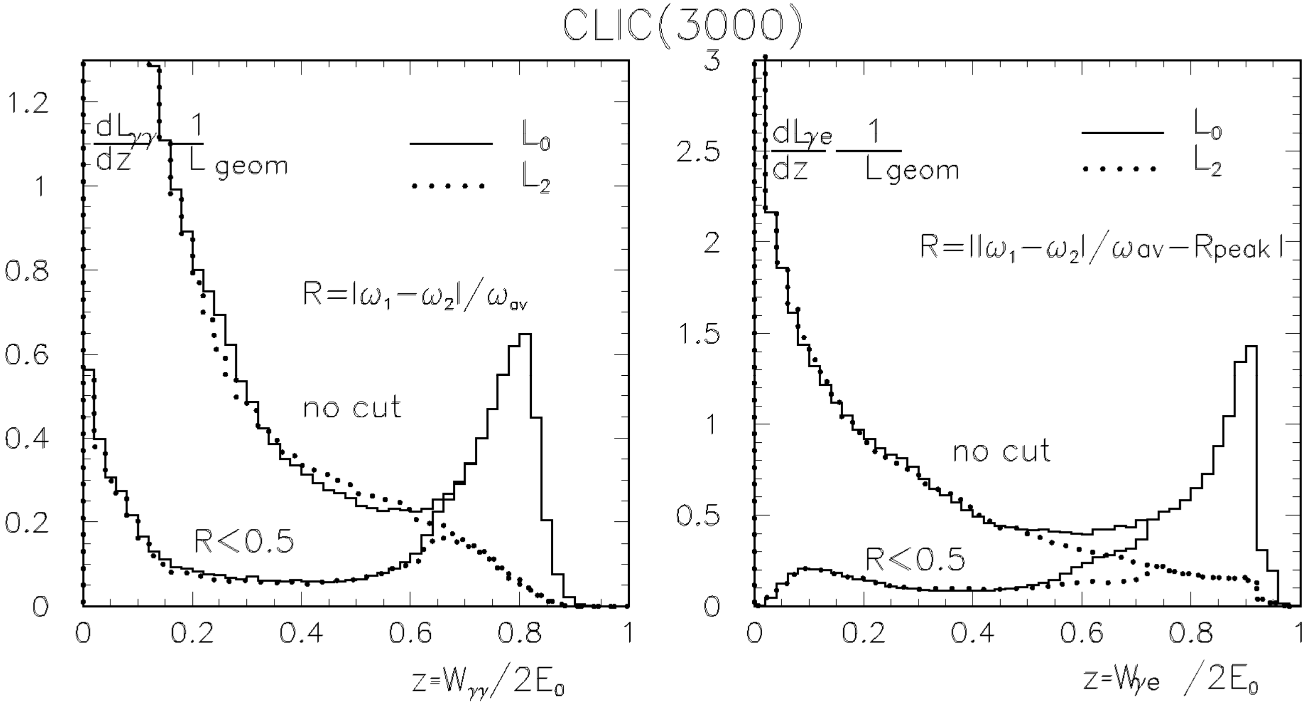
For CLIC(500)

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

$L_{\gamma\gamma}(z>0.8z_m) \sim 3\cdot 10^{33}$ 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.

$L_{\gamma\gamma}(z>0.8z_m) \sim 8\cdot 10^{33}$

(may be for not latest parameters)

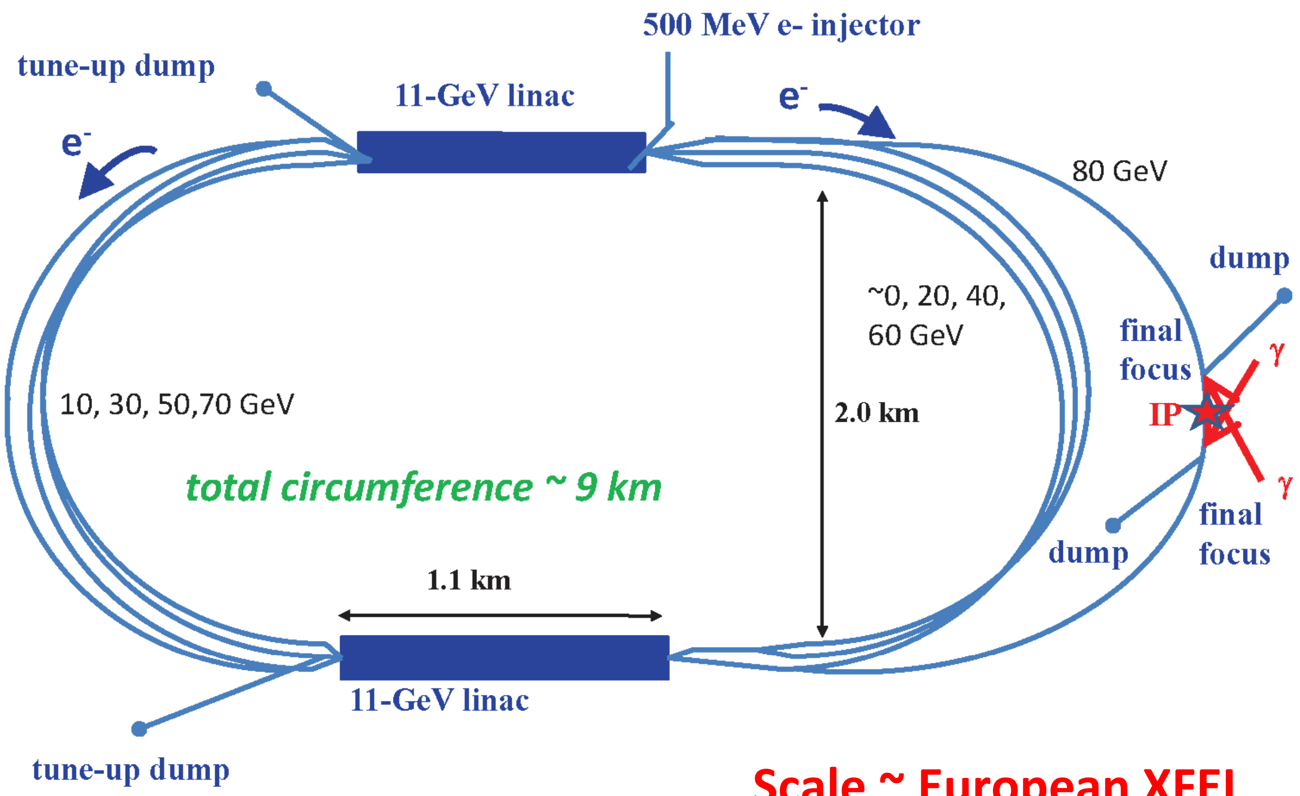
Photon collider Higgs factory
SAPPHiRE

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



Scale ~ European XFEL
~ 1 Billion ???

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

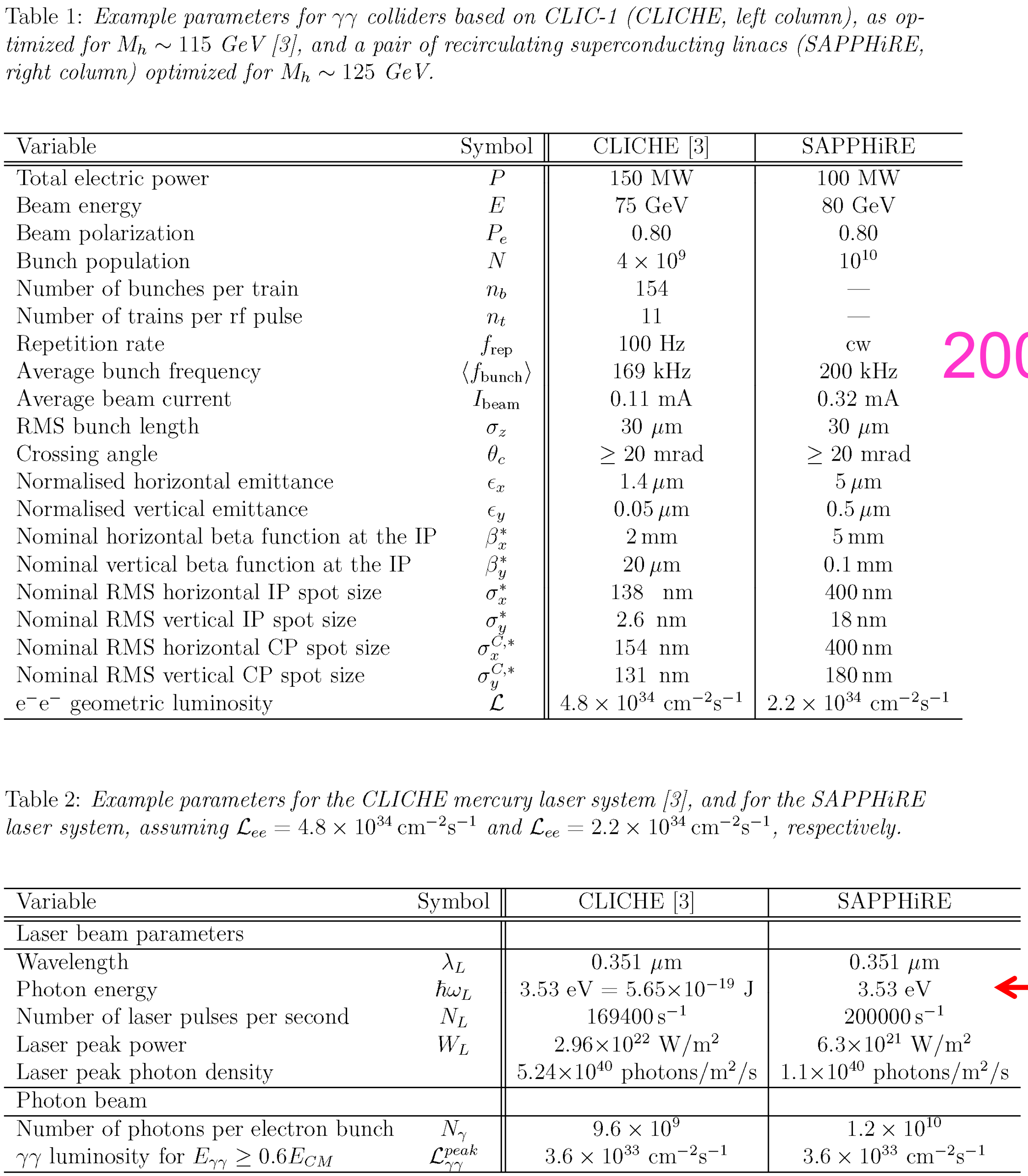


Table 1: *Example parameters for $\gamma\gamma$ colliders based on CLIC-1 (CLICHE, left column), as optimized for $M_h \sim 115$ GeV [3], and a pair of recirculating superconducting linacs (SAPPHiRE, right column) optimized for $M_h \sim 125$ GeV.*

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	$f_{\rm rep}$	100 Hz	cw
Average bunch frequency	$\langle f_{\rm bunch} \rangle$	169 kHz	200 kHz
Average beam current	$I_{\rm beam}$	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 $\mathcal{L}_{ee} = 4.8 \times 10^{34}\,{\rm cm}^{-2}{\rm s}^{-1}$ and $\mathcal{L}_{ee} = 2.2 \times 10^{34}\,{\rm cm}^{-2}{\rm s}^{-1}$, 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?

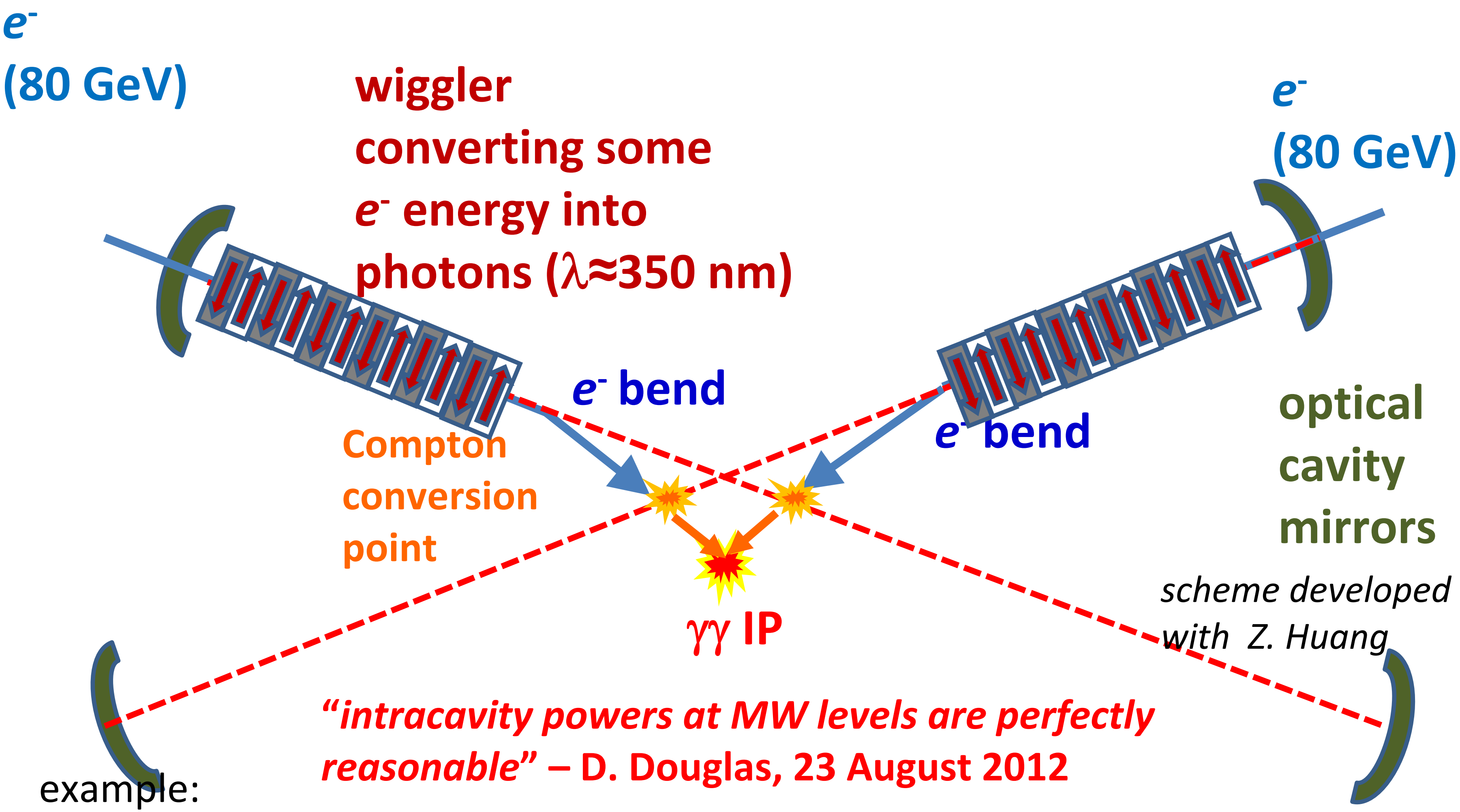
6. The PLC with E=80 GeV and λ=1.06/3 μm have very low energy final electrons with energies down to E=2 GeV. This courses very large disruption angles in the field of opposing beam and due to deflection in the solenoid field (due to crab crossing). Namely due to this reason TESLA (ILC) always considered 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!)



scheme developed with Z. Huang

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

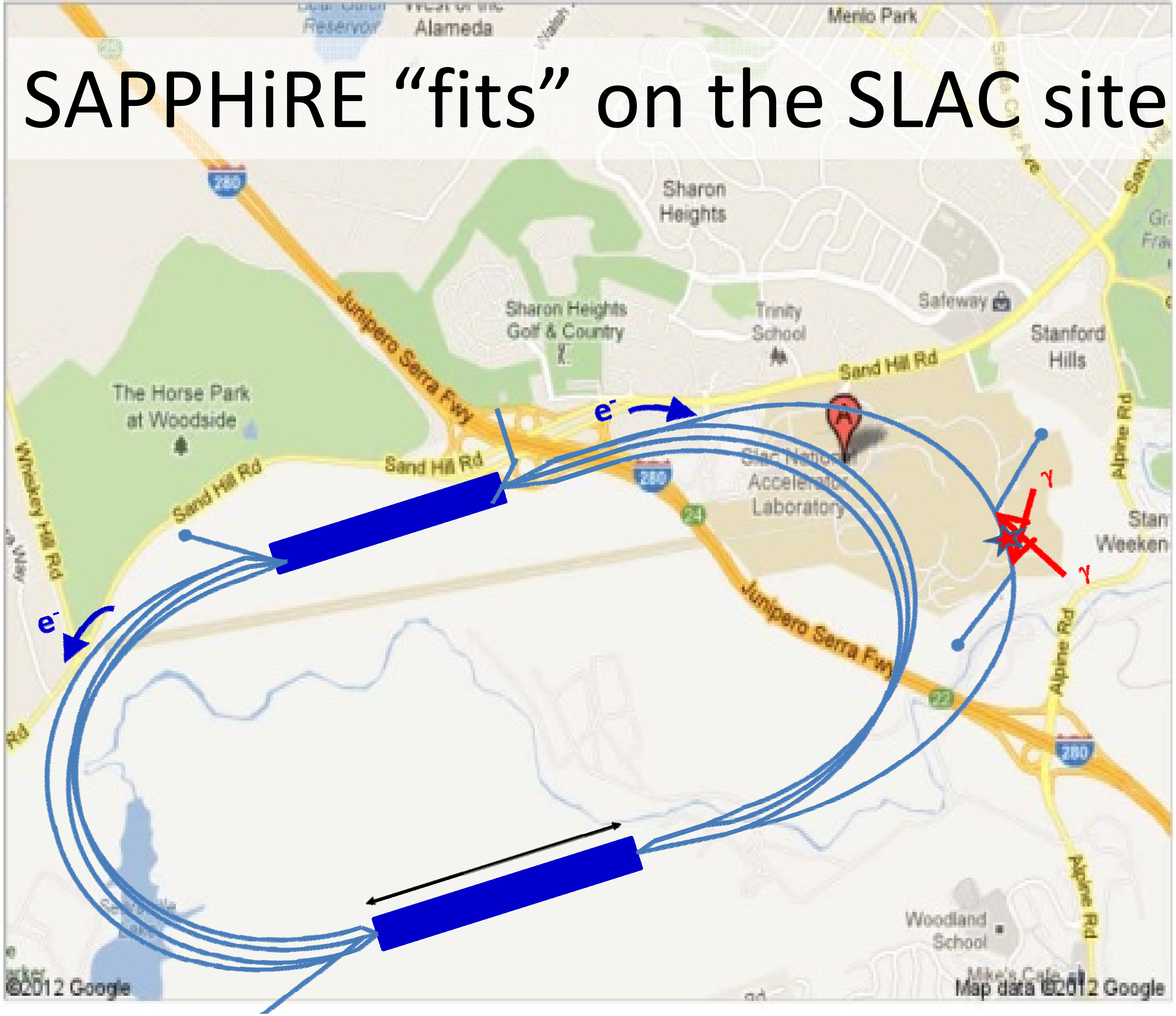
example:

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

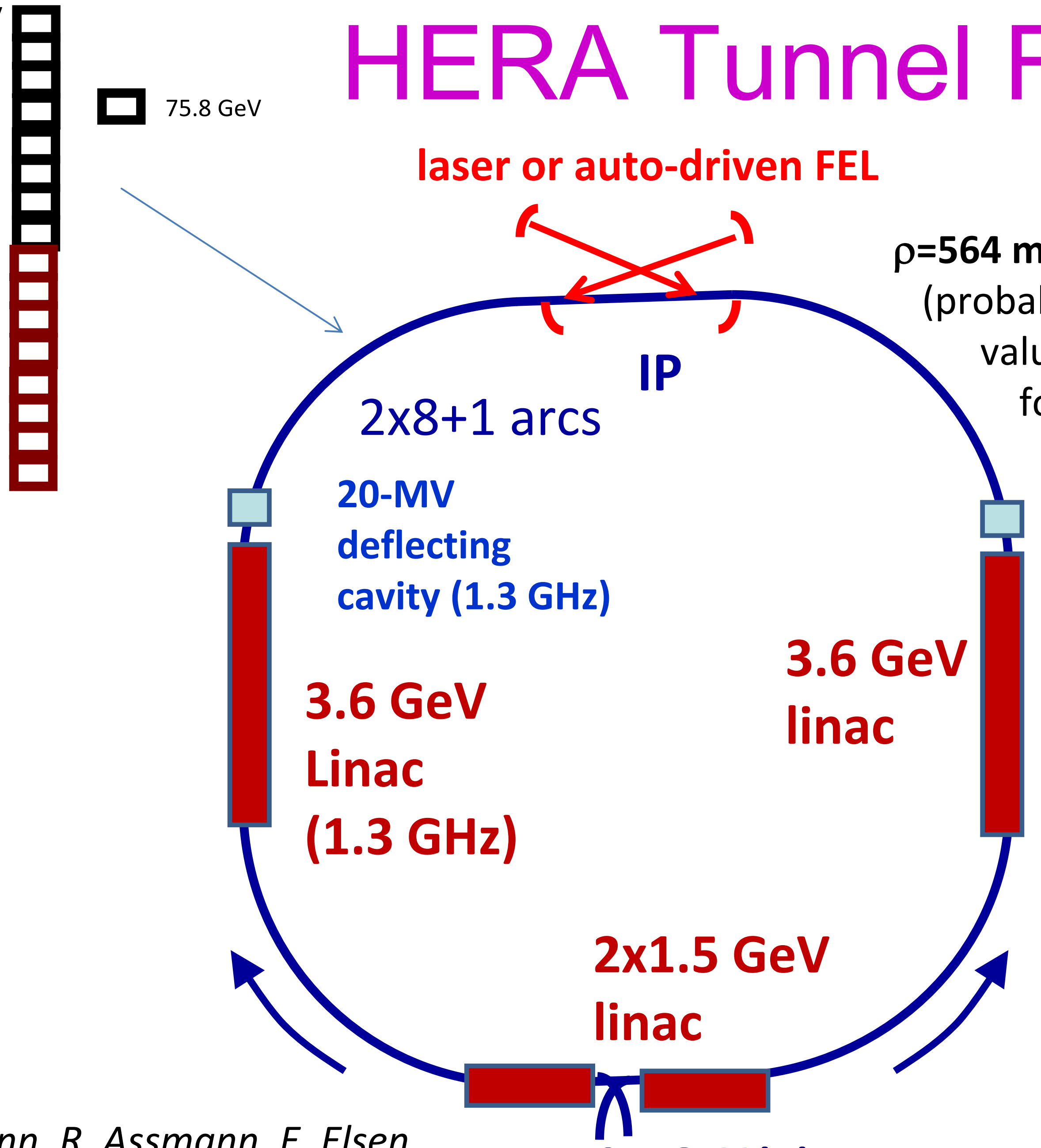
Sapphire has stimulated many other proposals of ring gamma-gamma Higgs factories:

from F.Zimmermann talks

SAPPHiRE “fits” on the SLAC site



HERA Tunnel Filler



arc magnets -17 passes!

beam 1
5.6 GeV
15.8
26.0
36.2
46.0
55.3
63.8
71.1

75.8 GeV

beam 2
71.1
63.8
55.2
46.0
36.2
26.0
15.8
5.6

laser or auto-driven FEL

IP

2x8+1 arcs

20-MV deflecting cavity (1.3 GHz)

3.6 GeV Linac (1.3 GHz)

3.6 GeV linac

20-MV deflecting cavity

2x1.5 GeV linac

0.5 GeV injector

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

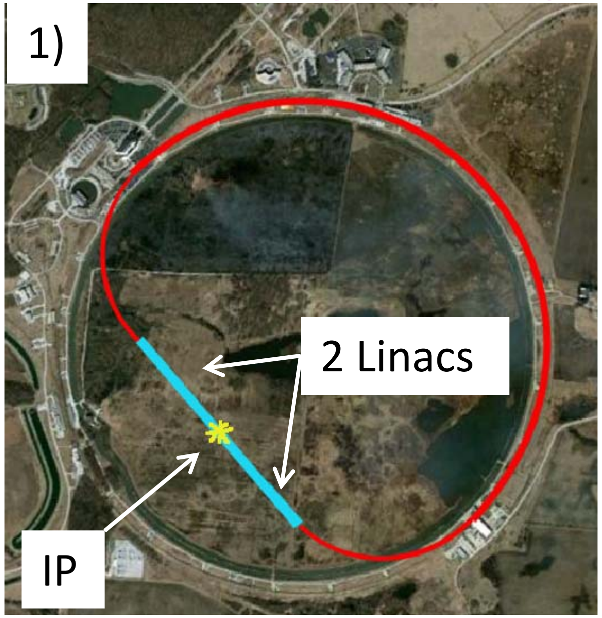
103 GeV Electron energy
γ c.o.m. 170 GeV

Possible Configurations at FNAL

Edward Nissen

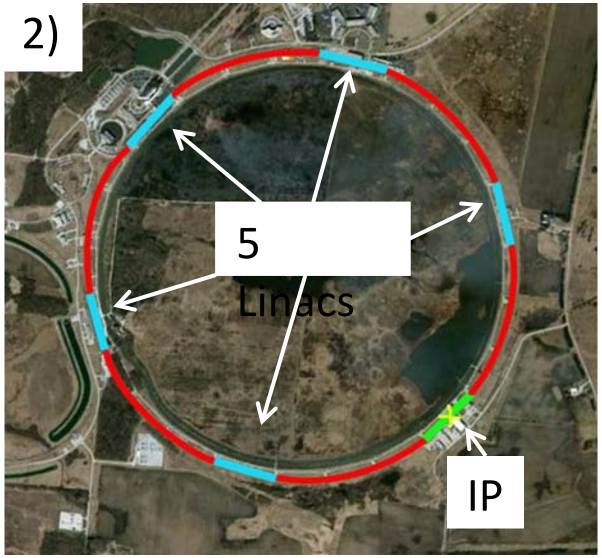
Tevatron Tunnel Filler Options

1)



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

2)



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

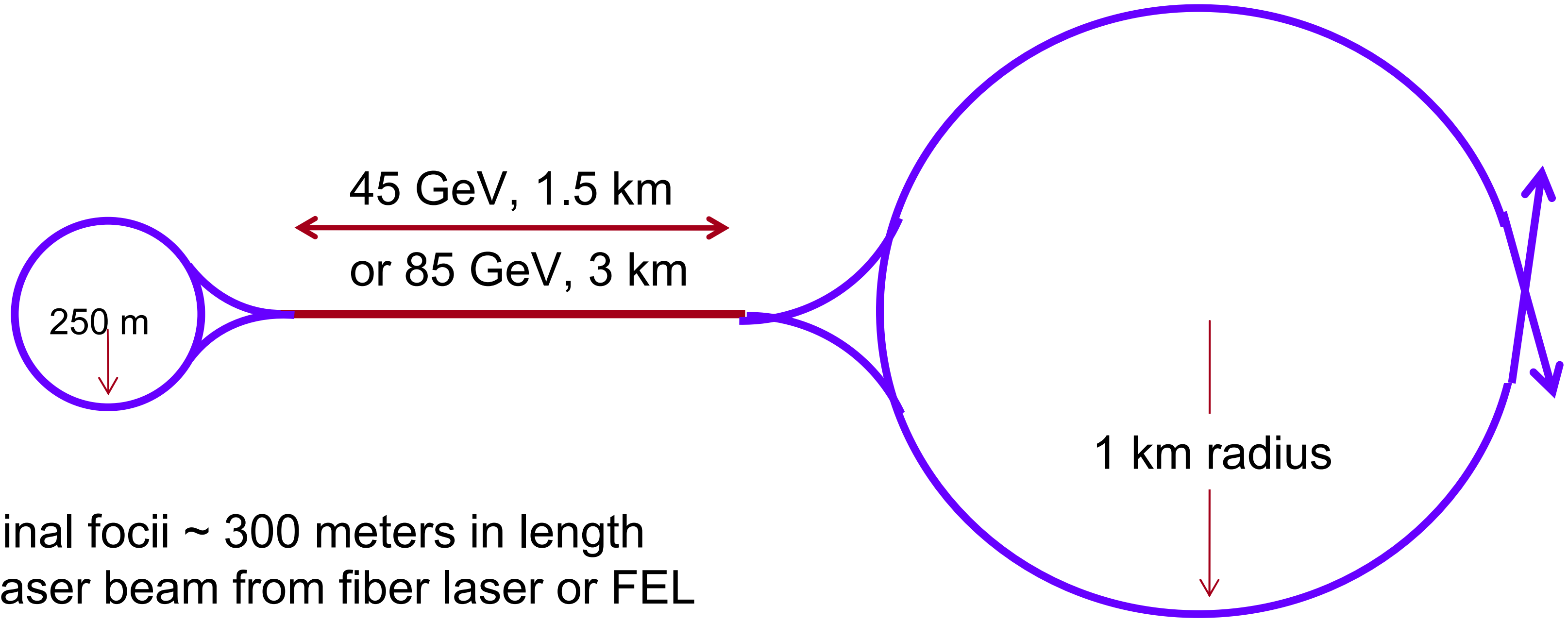
- Both versions assume an effective accelerating gradient of 23.5 MeV/m
- Option 1: would require more civil construction, but would only require two sets of spreader /recombiner magnets, and only two linacs, for greater simplicity.
- Option 2: would require 10 sets of spreader /recombiner magnets and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

SLC-ILC-Style (SILC) Higgs Factor

(T. Raubenheimer)

- Some challenges with 2-pass design!

1.6 B$ without laser



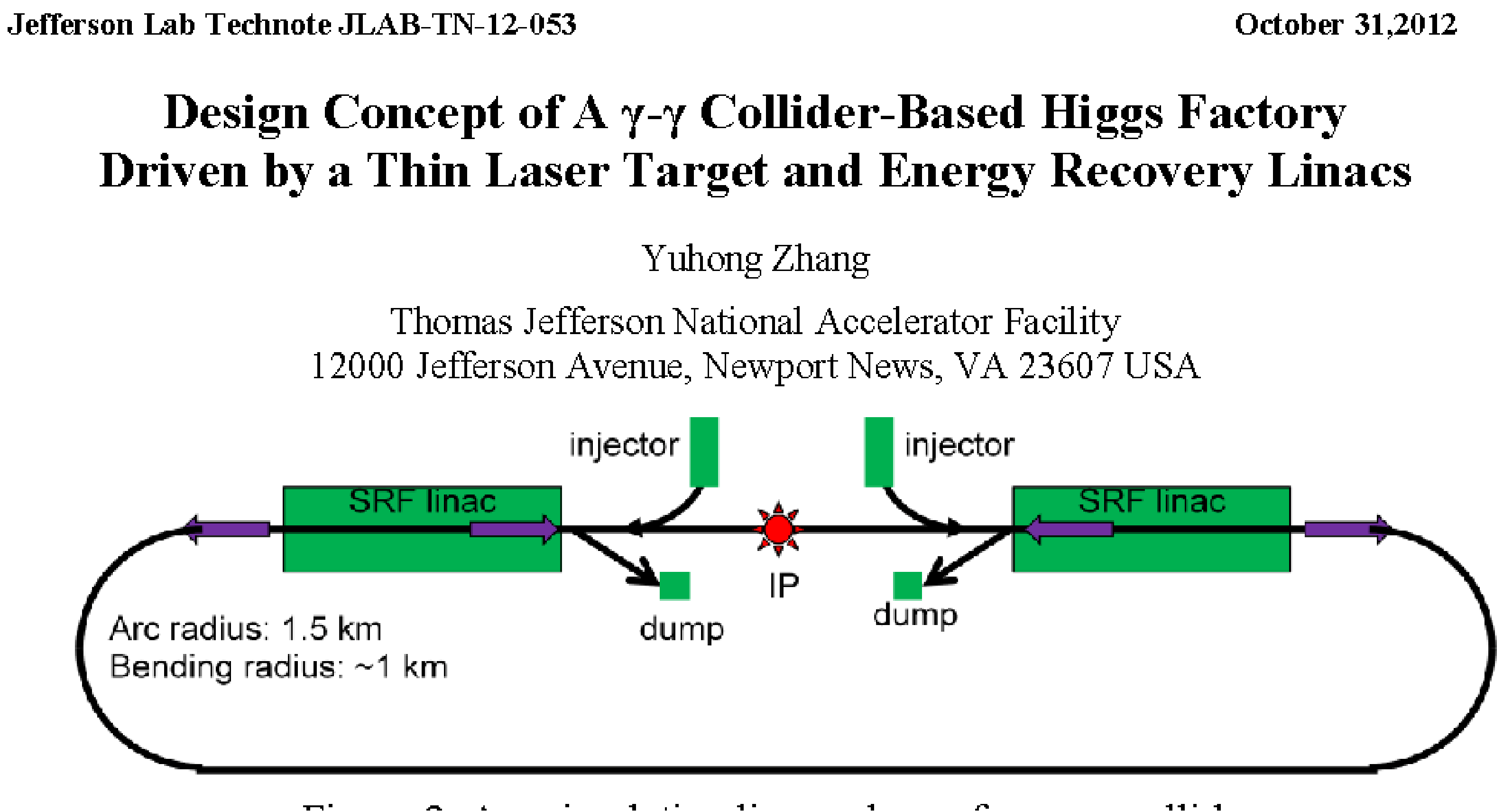
45 GeV, 1.5 km

or 85 GeV, 3 km

250 m

1 km radius

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.

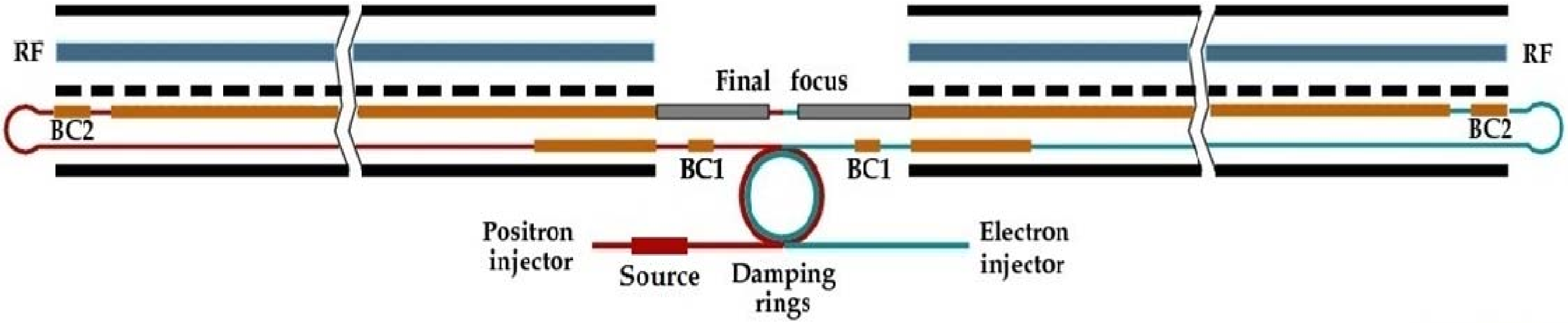
It does not work:

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

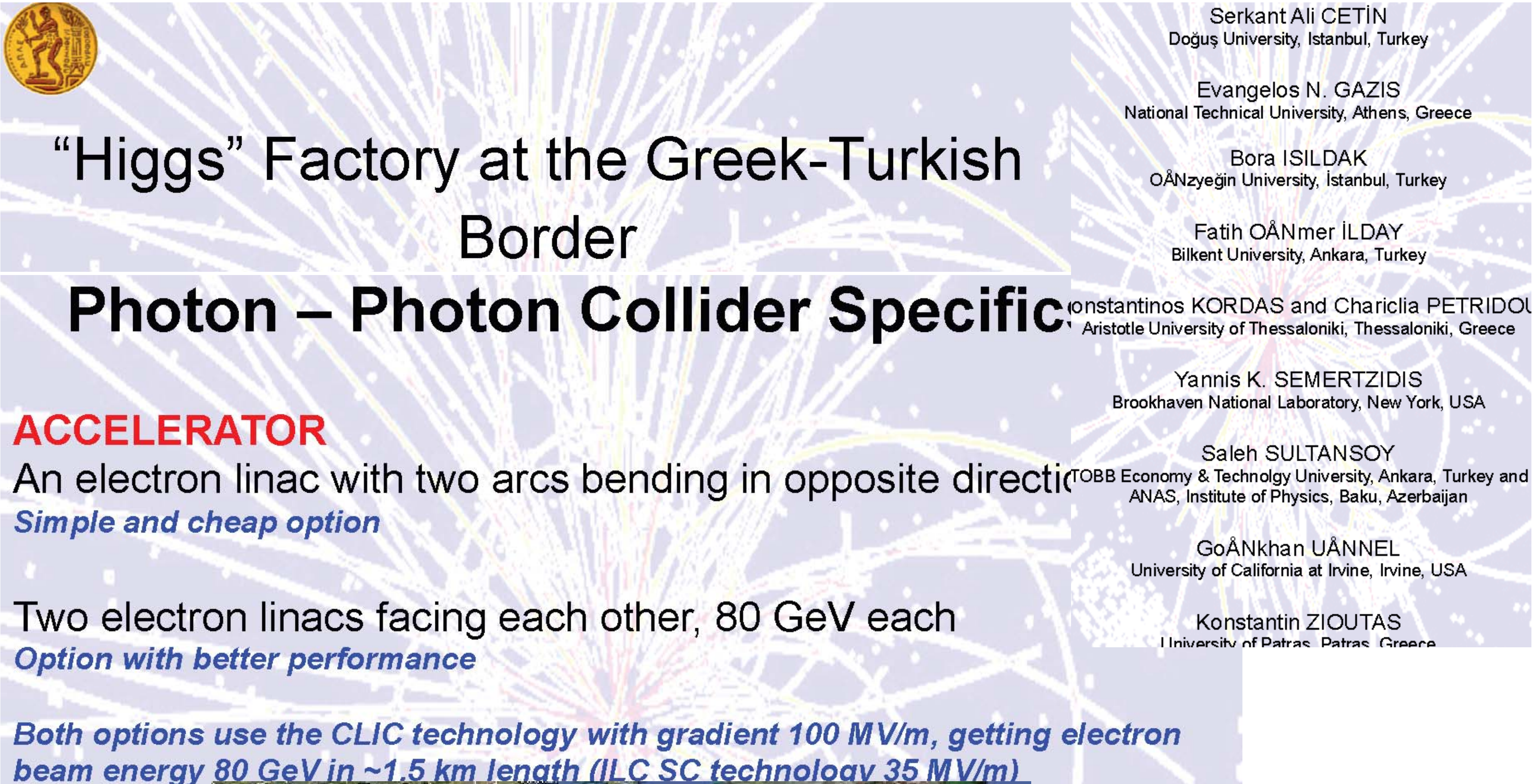
b) there is no improvement of luminosity, only decrease, because emittance increases with the increase of N. Maximum L for k~1.

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 directi

Simple and cheap option

Two electron linacs facing each other, 80 GeV each

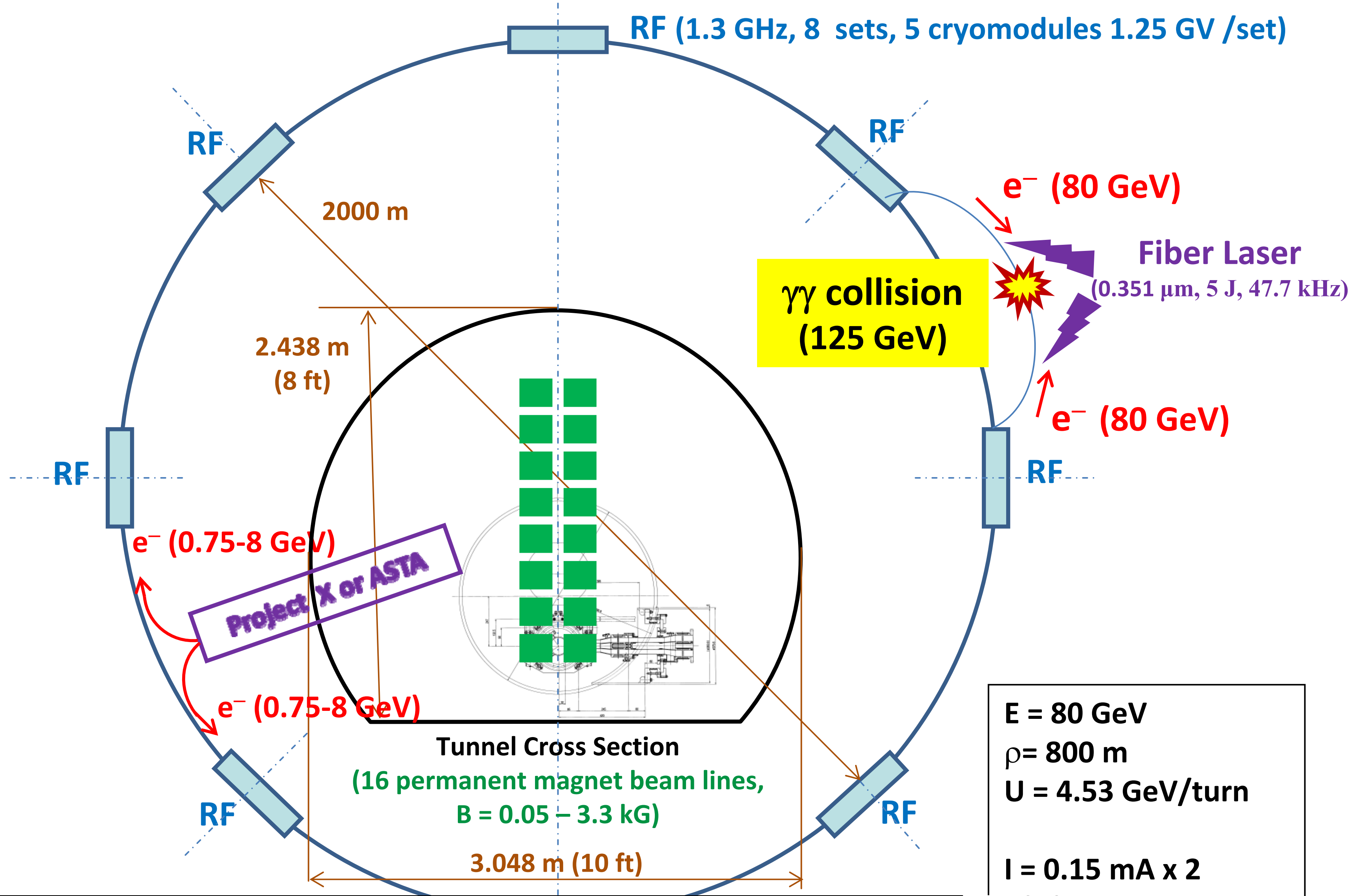
Option with better performance

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 !

(SLC type based on CLIC technology)

HFiTT: Higgs Factory in Tevatron Tunnel



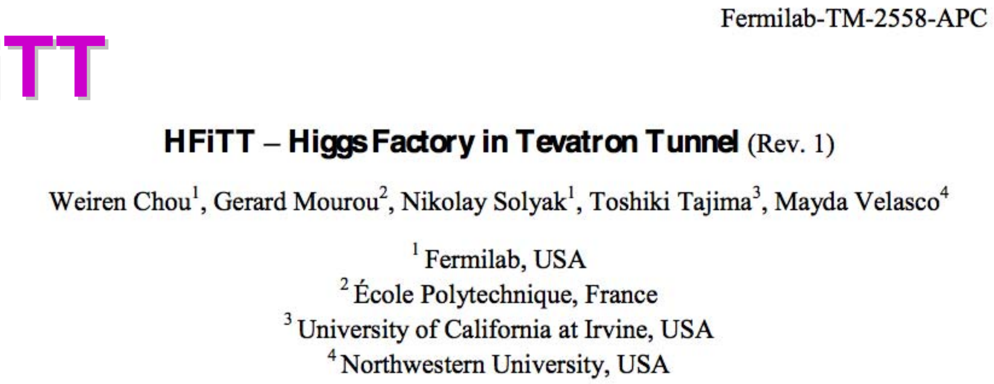
E = 80 GeV
ρ= 800 m
U = 4.53 GeV/turn

I = 0.15 mA x 2
(rf) = 27 MW

Energy loss per turn (at 80 GeV)	GeV	4.53

Cost estimate for HFiTT

M.Velasco, Photon2013

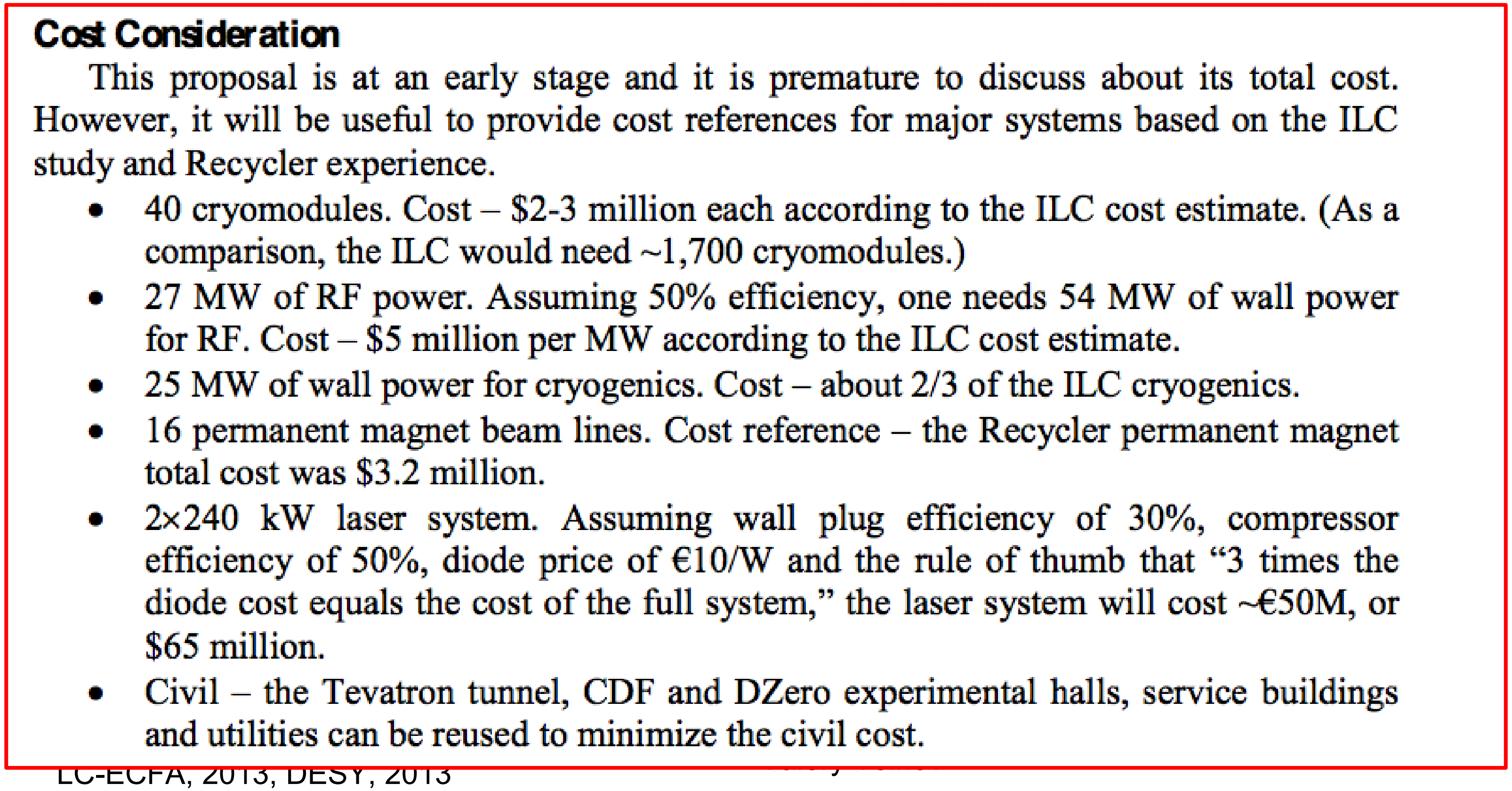


Fermilab-TM-2558-APC

HFiTT – Higgs Factory in Tevatron Tunnel (Rev. 1)

Weiren Chou[1], Gerard Mourou[2], Nikolay Solyak[1], Toshiki Tajima[3], Mayda Velasco[4]

[1] Fermilab, USA
[2] École Polytechnique, France
[3] University of California at Irvine, USA
[4] Northwestern University, USA



Cost Consideration

This proposal is at an early stage and it is premature to discuss about its total cost. However, it will be useful to provide cost references for major systems based on the ILC study and Recycler experience.

- 40 cryomodules. Cost – \$2-3 million each according to the ILC cost estimate. (As a comparison, the ILC would need ~1,700 cryomodules.)
- 27 MW of RF power. Assuming 50% efficiency, one needs 54 MW of wall power for RF. Cost – \$5 million per MW according to the ILC cost estimate.
- 25 MW of wall power for cryogenics. Cost – about 2/3 of the ILC cryogenics.
- 16 permanent magnet beam lines. Cost reference – the Recycler permanent magnet total cost was \$3.2 million.
- 2×240 kW laser system. Assuming wall plug efficiency of 30%, compressor efficiency of 50%, diode price of €10/W and the rule of thumb that "3 times the diode cost equals the cost of the full system," the laser system will cost ~€50M, or \$65 million.
- Civil – the Tevatron tunnel, CDF and DZero experimental halls, service buildings and utilities can be reused to minimize the civil cost.

< 1Billion USD

With Laser

Parameters of HFiTT,Sapphire,SILC

M.Velasco, Photon2013

Parameter	HFiTT	Sapphire	SILC
cms e-e- Energy	160 Gev	160 GeV	160 GeV
Peak $\gamma\gamma$ Energy	126 GeV	128 GeV	130 GeV
Bunch charge	2e10	1e10	5e10
Bunches/train	1	1	1000
Rep. rate	47.7 kHz	200 kHz	10 Hz
Power per beam	12.2 MW	25 MW	7 MW
CP from IP	1.2 mm	1 mm	4 mm
Laser pulse energy	5 J	4 J	1.2 J

Total electric power		< = 100 MW

M.Velasco, Photon2013

Option #1:
Fiber Lasers -- Significant breakthrough

Gerard Mourou et al., *“The future is fiber accelerators,” Nature Photonics, vol 7, p.258 (April 2013).*

ICAN – International Coherent Amplification Network

Figure 2: Principle of a coherent amplifier network (CAN) based on fiber laser technology. An initial pulse from a seed laser (1) is stretched (2), and split into many fibre channels (3). Each channel is amplified in several stages, with the final stages producing pulses of ~1 mJ at a high repetition rate (4). All the channels are combined coherently, compressed (5) and focused (6) to produce a pulse with an energy of >10 J at a repetition rate of 10 kHz (7). [3]

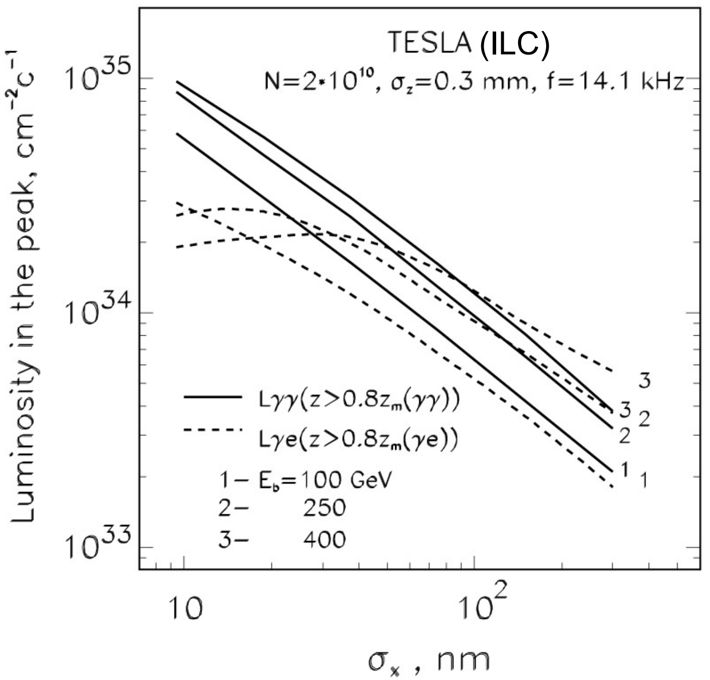
We need 5 J at ~40kHz!

My dreams of $\gamma\gamma$ factories

(PLC 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!

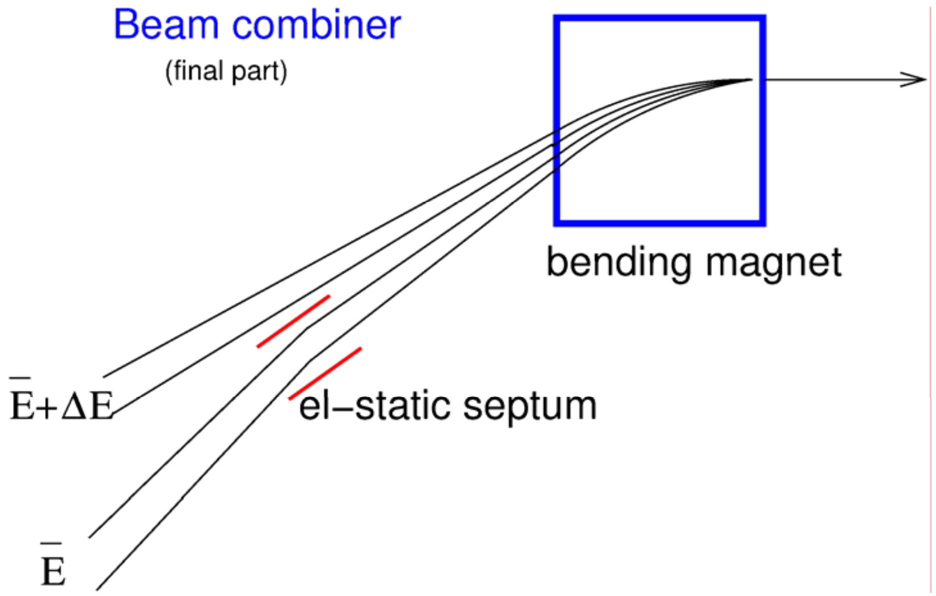
So, photoguns have much smaller longitudinal emittances than it is needed for linear collider (both e+e- or $\gamma\gamma$).

How can we use this fact?

A proposed method

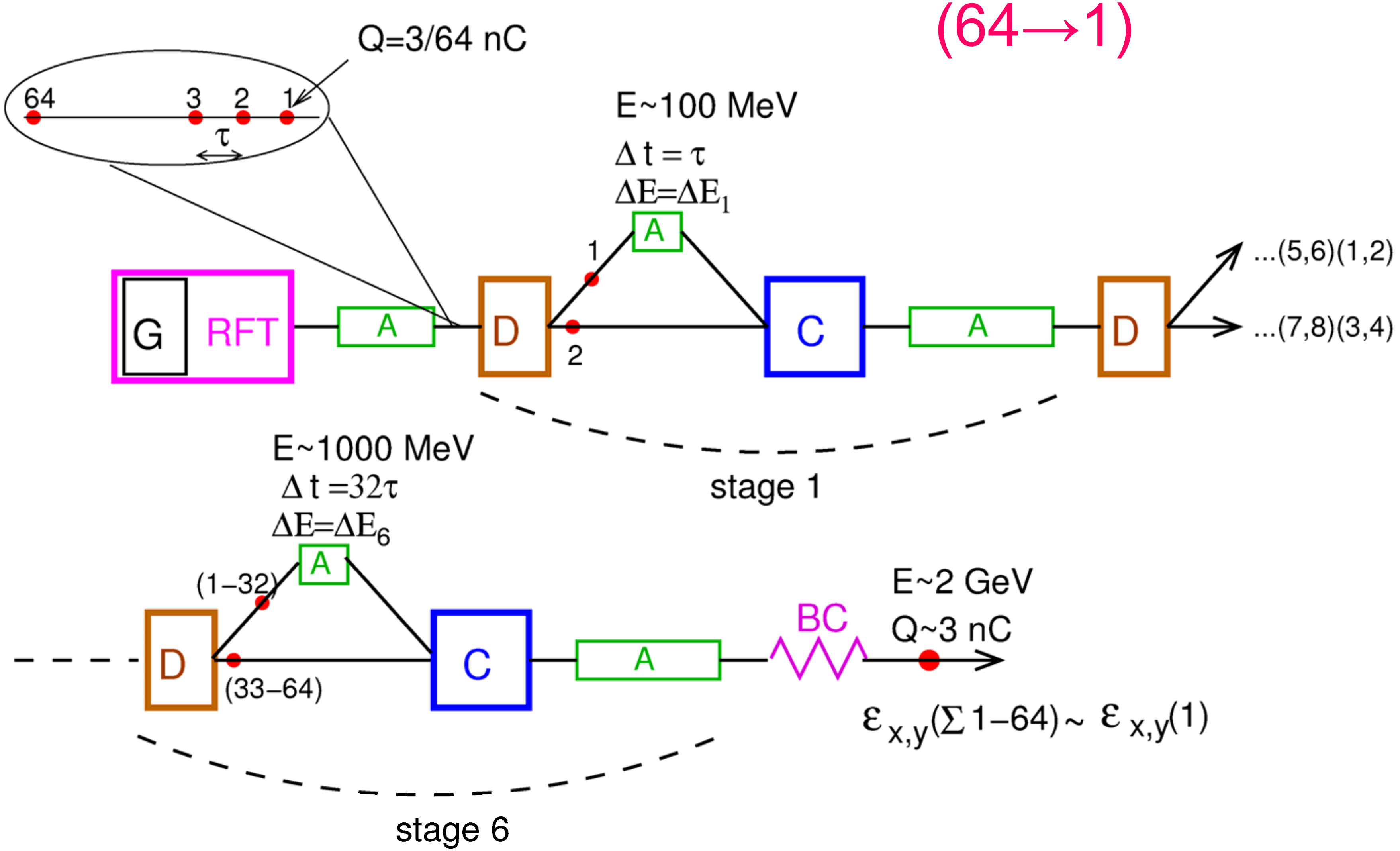
Let us combine many low charge, low emittance beams from photo-guns to one bunch using some differences in their energies. The longitudinal emittance increases approximately proportionally to the number of combined bunches while the transverse emittance (which is most important) remains almost constant.

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: $N=2\cdot10^{10}$ (Q~3 nC), $\sigma_z=0.4$ mm

Damping rings(RDR): $\varepsilon_{nx}=10^{-3}$ cm, $\varepsilon_{ny}=3.6\cdot10^{-6}$ cm, $\beta_x=0.4$ cm, $\beta_y=0.04$ cm,

RF-gun (Q=3/64 nC) $\varepsilon_{nx}\sim10^{-4}$ cm, $\varepsilon_{ny}=10^{-6}$ cm, $\beta_x=0.1$ cm, $\beta_y=0.04$ cm,

The ratio of geometric luminosities

$$L_{RFgun}/L_{DR}=\sim10$$

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.

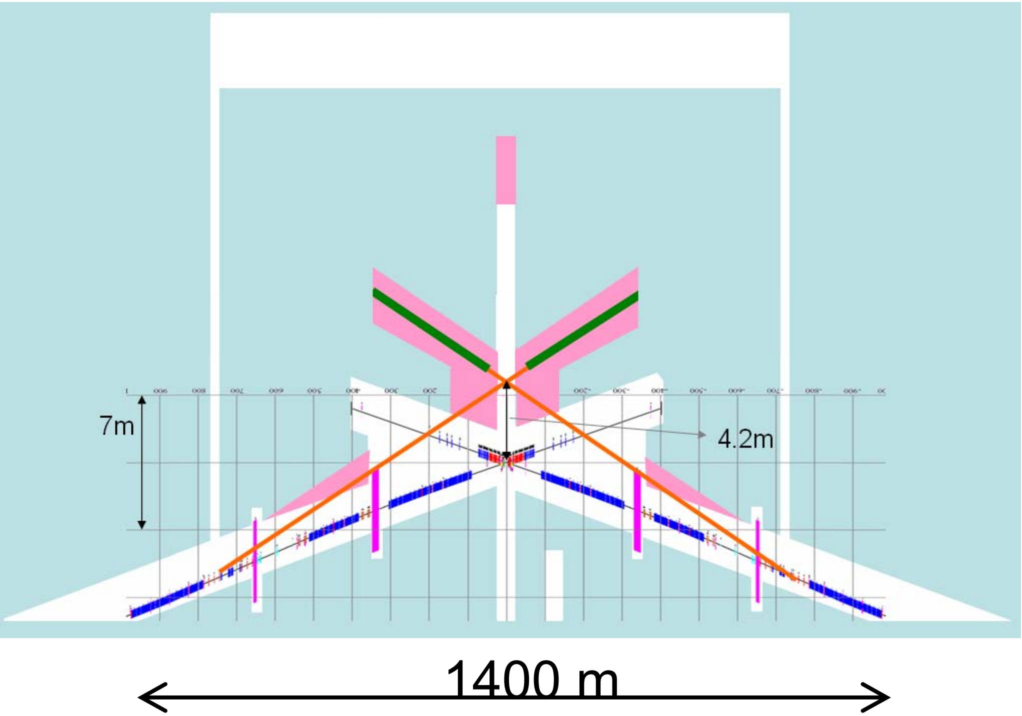
  All PLC for Higgs without e+e- has not sufficient physics case.
- PLC without damping rings is possible, could have even higher (or much higher) luminosity, needs further study. That could open the way to γγ factories, to precision measurement of the Higgs self coupling etc (if there is any new physics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

Conclusion (cont.)

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)

The scheme of upgrade from 14 to 25 mrad

LCWS 2006



- additional angle is 5.5mrad and shift of detector by about 3-4 m