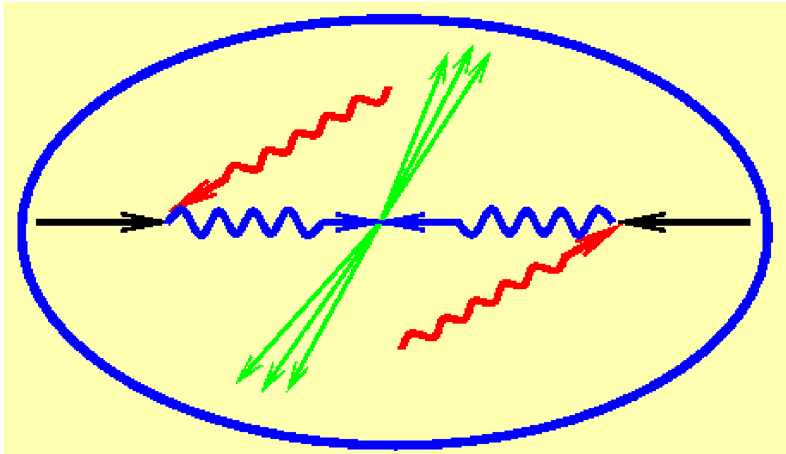


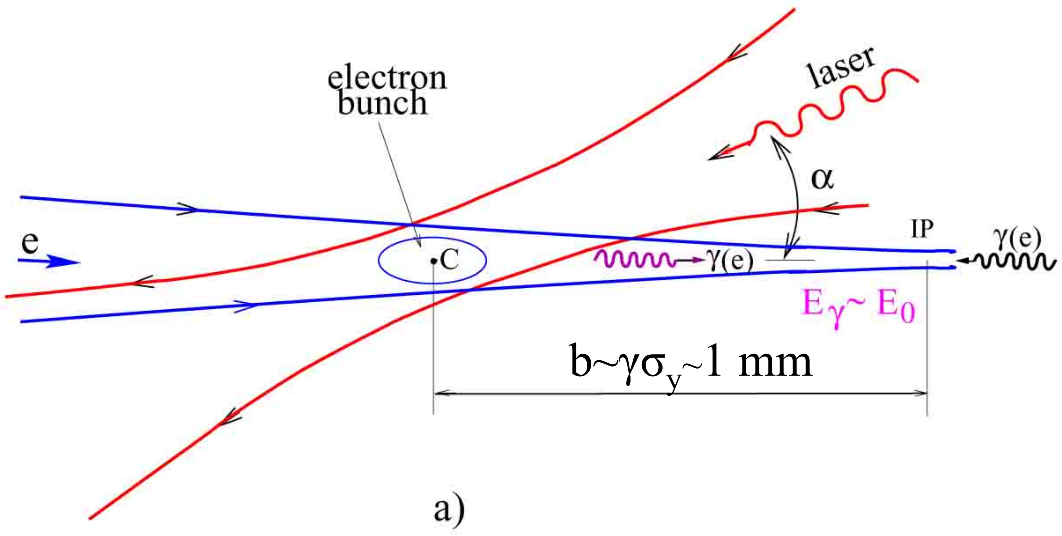
Photon collider: summary

Valery Telnov

Budker INP, Novosibirsk

LC-ECFA-2013, DESY, May 31

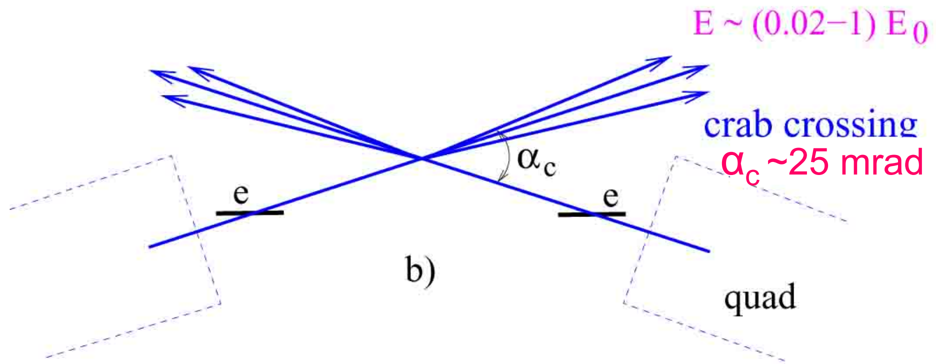
Scheme of $\gamma\gamma$, γe collider



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

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

$E_0 = 250$ 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.

ω_{max}~0.8 E_0

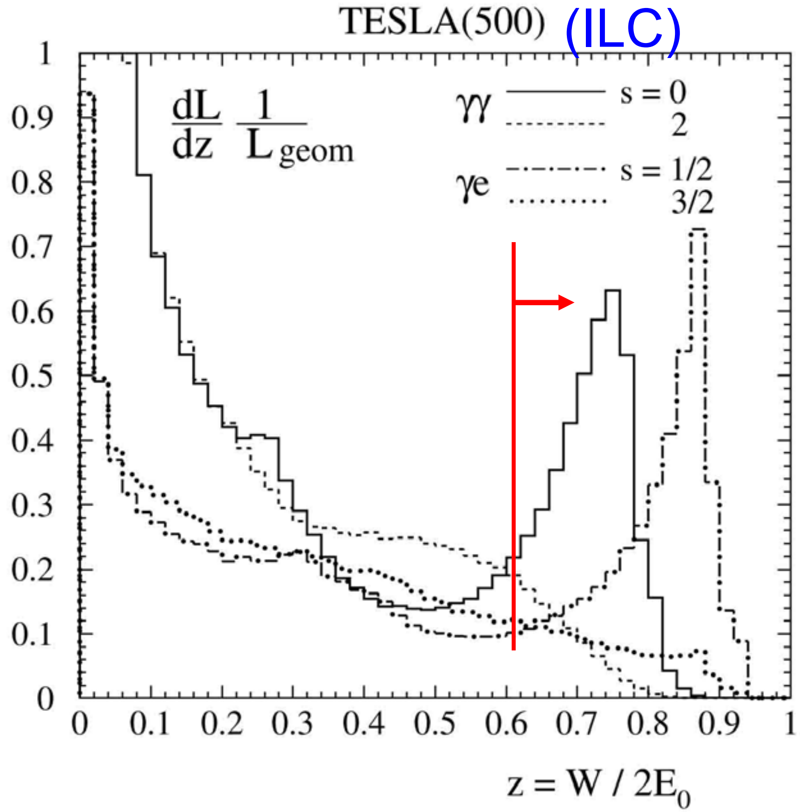
$W_{\gamma\gamma,\ max} \sim 0.8\cdot 2E_0$
$W_{\gamma e,\ max} \sim 0.9\cdot 2E_0$

For the Higgs factory one needs E_0~105 GeV, λ~1 μm

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

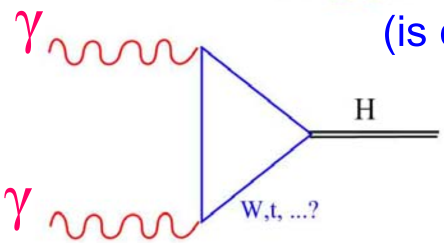
$L_{\gamma\gamma}(z>0.8z_m) \sim 0.1\ L_{e-e-}(\text{geom})$

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

The resonance Higgs production is one of the gold-plated processes for PLC

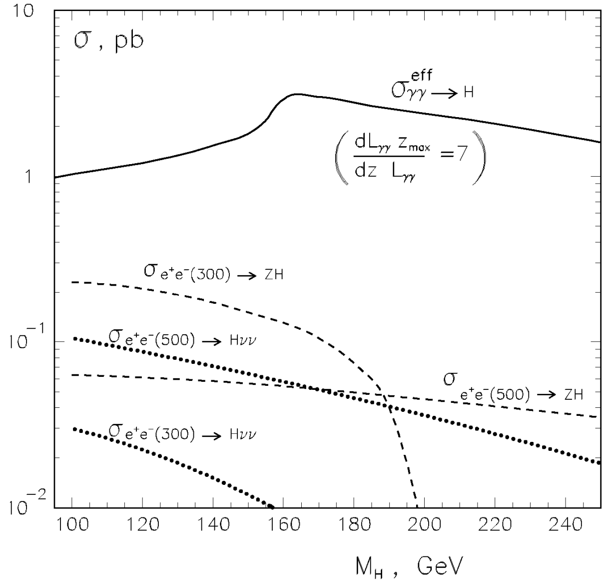
Higgs boson

(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

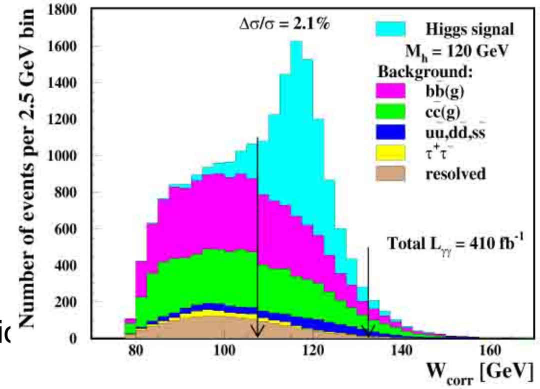


V.T,1999

H→bb

realistic simulation P.Niezurawski et al

(previ

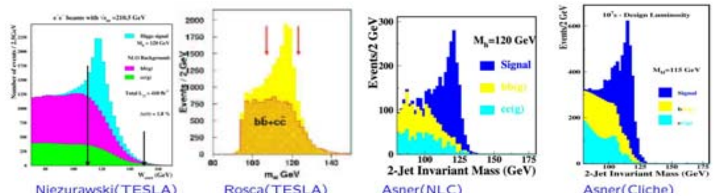


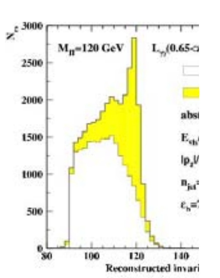
$$\dot{N}_{\gamma\gamma \to H} = L_{\gamma\gamma} \times \frac{dL_{\gamma\gamma} M_H}{dW_{\gamma\gamma} L_{\gamma\gamma}} \frac{4\pi^2 \Gamma_{\gamma\gamma}(1+\lambda_1\lambda_2)}{M}$$

At ILC

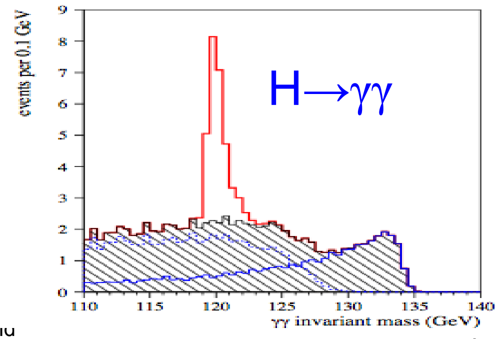
$$\frac{N(\gamma\gamma \to H)}{N(e^+e^- \to H + X)} \sim 1 - 10$$

For M_H=115-250 GeV





S.Soldner-Rembold
(thr first simulation)



At nominal luminosities the number of Higgs in $\gamma\gamma$ will be similar to that in e+e-. The effective cross section (in terms of e-e- luminosity) is about 200 fb.

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 (using photon polarizations). In order to get $\Gamma(H\to\gamma\gamma)$ one needs $Br(H\to bb)$ from e+e-. This gives also Γ_{tot}.

e+e- can also measure Br(bb, cc, gg, ττ, μμ, invisible), Γ_{tot} , less backgrounds due to tagging of Z.

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

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

The discovery of the Higgs have led to appearance of many projects of Higgs factories, among them about ten projects of gamma-gamma Higgs factories without e+e- :

Higgs Factories Dreams

γγ Higgs factories appeared in 2012-2013 years

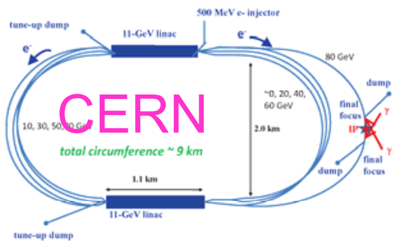
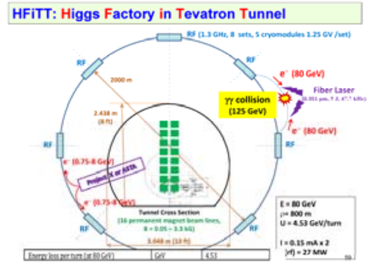


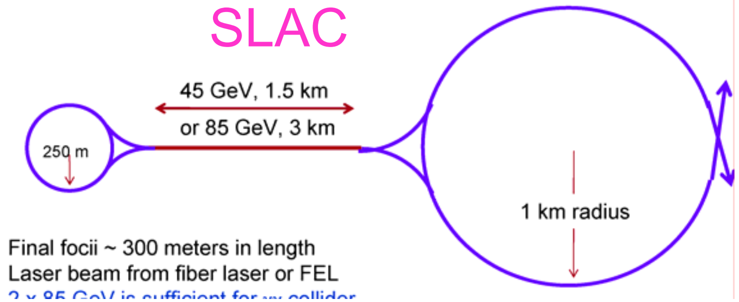
Figure 3: Sketch of a layout for a γγ collider based on recirculating superconducting linacs – the SAPPHiRE concept.



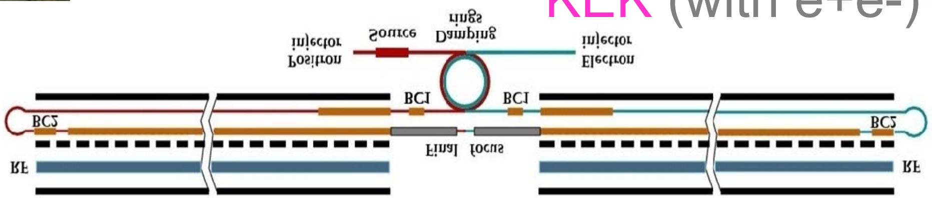
FNAL

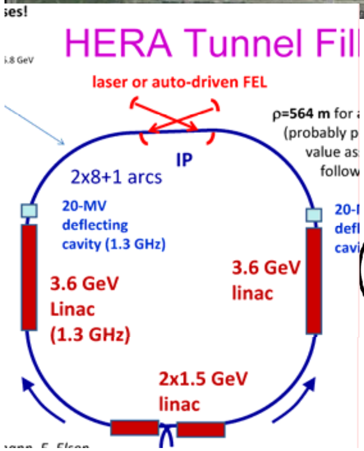
JLAB

FNAL

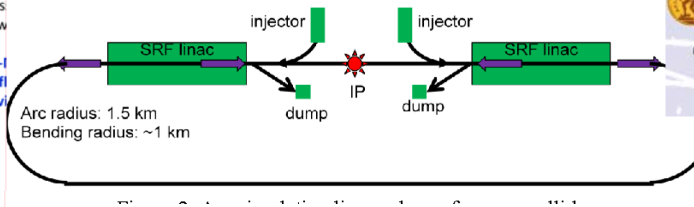


KEK (with e+e-)





JLAB



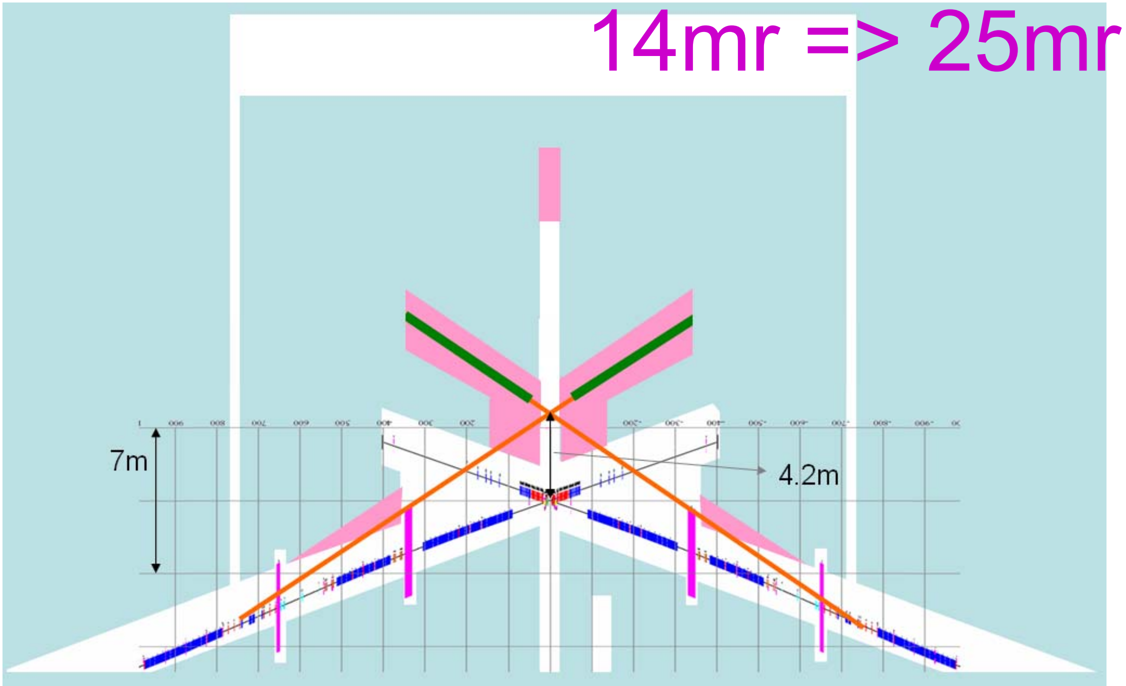
In my opinion, these projects look not serious (because without e+e-), but demonstrate the interest of physics community to photon colliders.

Much more natural, realistic and physics motivated are $\gamma\gamma$, γe colliders based on e+e- projects ILC and CLIC.

Unfortunately, since 2006 GDE considered only the baseline ILC (only e+e-) without any options and at present the ILC design is incompatible with the photon collider.

It is still not too late to make necessary modifications:

- the second IP or space for the crossing angle 25 mrad;
- space for the beamdump;
- space for a laser system.



Parameters for the Linear Collider

Update November 20, 2006

The ILC scope document, 2006

2. Baseline Machine

4. Options beyond the Baseline machine

Timing and priorities of the options will depend on the results obtained at the LC baseline 500 GeV machine and possibly at the energy upgraded machine, together with the results from the LHC. An important issue here

- Several physics measurements are uniquely enabled through collisions of (polarized) photons, or electrons and photons, from backscattered laser beams. High polarization of both electron beams is required. This option will require transformation of one interaction region to run as a $\gamma\gamma$ or $e\gamma$ collider at any energy up to 80% of the e^+e^- maximum energy, with reduced luminosity (some 30-50%) with respect to the e^+e^- luminosity. It is desired to keep the option of providing a second beam delivery system without major interruption. More studies on the technical aspects of a $\gamma\gamma$ or $e\gamma$ collider are required by the experimental community.

Asia: Sachio Komamiya, Dongchul Son
Europe : Rolf Heuer (chair), Francois Richard
North America: Paul Grannis, Mark Oreglia

One of the authors of the LC scope document was Sachio Komamiya and now being the head of the LC board he has a good opportunity to bring the ILC design in agreement with the scope document requirements.

It is really extremely important to make the required changes during this-next years.

The photon collider at ILC (TESLA) has been developed in detail at conceptual level, all simulated, all reported and published (TESLA TDR (2001) and updated later.

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.

10-15 years ago PLC community accounted >100 active people, we had several special PLC workshop.

Now the interest to PLC is not smaller but activity is much reduced (in the stand by mode) due to unmotivated exclusion (in 2006) of the PLC from the ILC project.

1 The Photon Collider at TESLA 2001

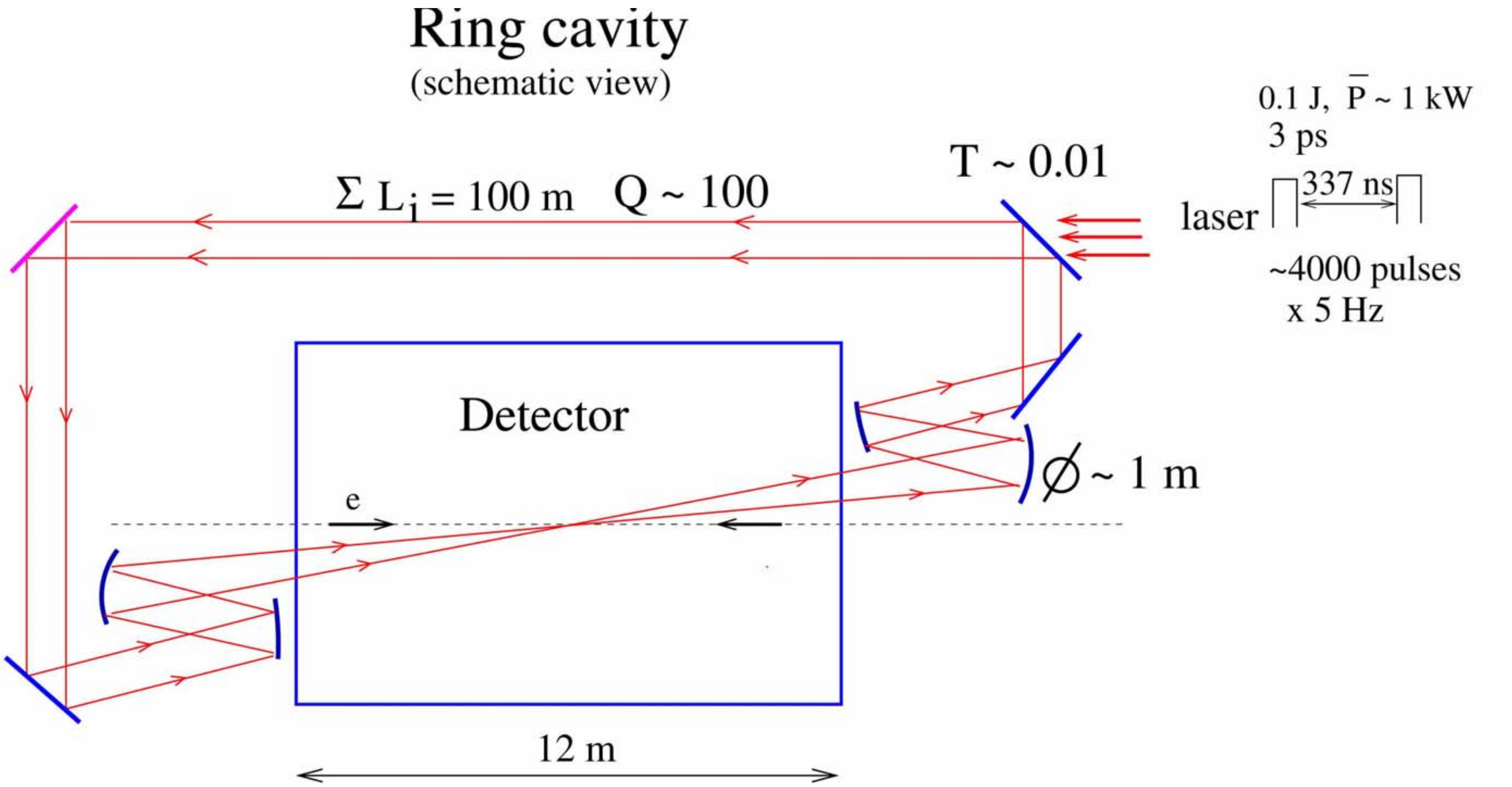
B. Badelek[43], C. Blöchinger[44], J. Blümlein[12], E. Boos[28], R. Brinkmann[12], H. Burkhardt[11], P. Bussey[17], C. Carimalo[33], J. Chyla[34], A.K. Çiftçi[4], W. Decking[12] A. De Roeck[11], V. Fadin[10], M. Ferrario[15], A. Finch[24], H. Fraas[44], F. Franke[44], M. Galynskii[27], A. Gamp[12], I. Ginzburg[31], R. Godbole[6], D.S. Gorbunov[28], G. Gounaris[39], K. Hagiwara[22], L. Han[19], R.-D. Heuer[18], C. Heusch[36], J. Illana[12], V. Ilyin[28], P. Jankowski[43], Yi Jiang[19], G. Jikia[16], L. Jönsson[26], M. Kalachnikow[8], F. Kapusta[33], R. Klanner[12,18], M. Klasen[12], K. Kobayashi[41], T. Kon[40], G. Kotkin[30] M. Krämer[14], M. Krawczyk[43], Y.P. Kuang[7], E. Kuraev[13], J. Kwiecinski[23], M. Leenen[12], M. Levchuk[27], W.F. Ma[19], H. Martyn[1], T. Mayer[44], M. Melles[35], D.J Miller[25], S. Mtingwa[29], M. Mühlleitner[12], B. Muryn[23], P.V. Nickles[8], R. Orava[2] C. Pancheri[15], A. Penin[12], A. Potylitsyn[42], P. Poulose[6], T. Quast[8], P. Raimondi[37], H. Redlin[8], F. Richard[32], S.D. Rindani[2], T. Rizzo[37], E. Saldin[12], W. Sandner[8], H. Schönnagel[8], E. Schneidmiller[12], H.J. Schreiber[12], S. Schreiber[12], K.P. Schüler[12], V. Serbo[30], A. Seryi[37], R. Shanidze[38], W. da Silva[33], S. Söldner-Rembold[11], M. Spira[35], A.M. Stasto[23], S. Sultansoy[5], T. Takahashi[21], V. Telnov[10,12], A. Tkabladze[12], D. Trines[12], A. Undrus[9], A. Wagner[12], N. Walker[12], I. Watanabe[3], T. Wengler[11], I. Will[8,12], S. Wipf[12], Ö. Yavaş[4], K. Yokoya[22], M. Yurkov[12], A.F. Zarnecki[43], P. Zerwas[12], F. Zomer[32].

[1] RWTH Aachen, Germany
[2] PRL, Ahmedabad, India
[3] Akita KeizaiHoka University, Japan
[4] Ankara University, Turkey
[5] Gazi University, Ankara, Turkey
[6] Indian Institute of Science, Bangalore, India
[7] Tsinghua University, Beijing, P.R. China
[8] Max–Born–Institute, Berlin, Germany
[9] BNL, Upton, USA
[10] Budker INP, Novosibirsk, Russia
[11] CERN, Geneva, Switzerland
[12] DESY, Hamburg and Zeuthen, Germany
[13] JINR, Dubna, Russia
[14] University of Edinburgh, UK
[15] INFN-LNF, Frascati, Italy
[16] Universität Freiburg, Germany
[17] University of Glasgow, UK
[18] Universität Hamburg, Germany
[19] CUST, Hefei, P.R.China
[20] University of Helsinki, Finland
[21] Hiroshima University, Japan
[22] KEK, Tsukuba, Japan
[23] INP, Krakow, Poland
[24] University of Lancaster, UK
[25] UCL, London, UK
[26] University of Lund, Sweden
[27] Inst. of Physics, Minsk, Belarus
[28] Moscow State University, Russia
[29] N.Carolina Univ., USA
[30] Novosibirsk State University, Russia
[31] Inst. of Math., Novosibirsk, Russia
[32] LAL, Orsay, France
[33] Université de Paris VI–VII, France
[34] IP, Prague, Czech Republic
[35] PSI, Villingen, Switzerland
[36] UCSC, Santa Cruz, USA
[37] SLAC, Stanford, USA
[38] Tbilisi State University, Georgia
[39] University of Thessaloniki, Greece
[40] Seikei University, Tokyo, Japan
[41] Sumimoto Heavy Industries, Tokyo, Japan
[42] Polytechnic Institute, Tomsk, Russia
[43] Warsaw University, Poland
[44] Universität Würzburg, Germany

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

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

H. Takahashi

4 mirror cavities are at the ATF

KEK-Hiroshima
installed 2011

relatively simple control system
employs new feed back scheme

LAL-Orsay
installed summer 2010

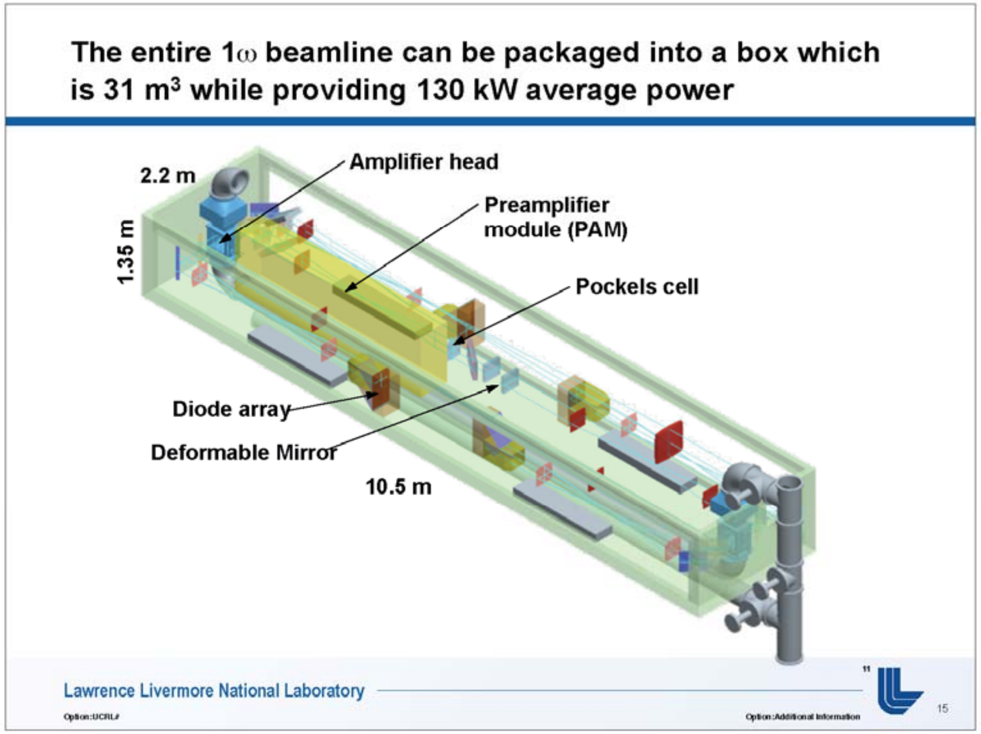
sophisticated control
digital PDH feedback

- **So far**
  - **2.6kW stored w/ enhancement of 1230**
  - **Highly stable ΔL~4pm**
  - **vertical laser size at the IP 13 μ m**
  - **120g/5bunches -> ~2.6 × 10^8/sec**
  - **Digital Feedback**
- **Quantitative understanding**
  - **Finesse**
  - **Powers**
  - **Profile**

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)

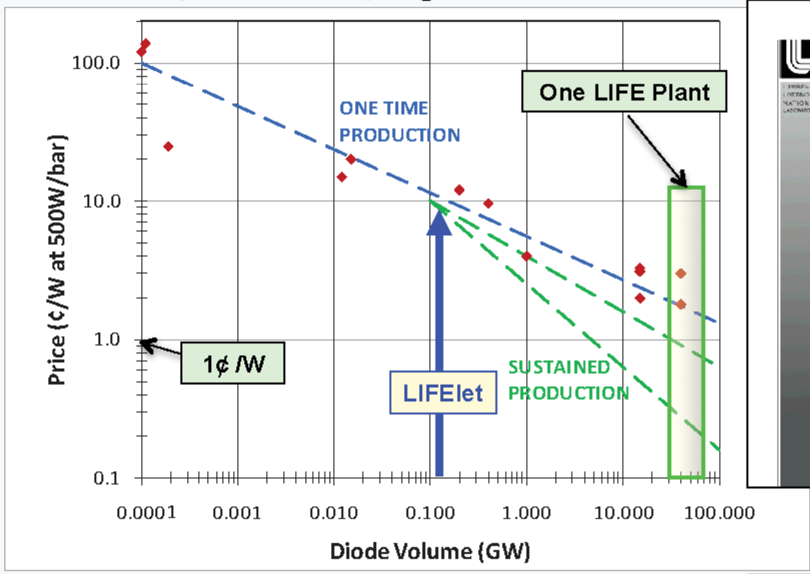


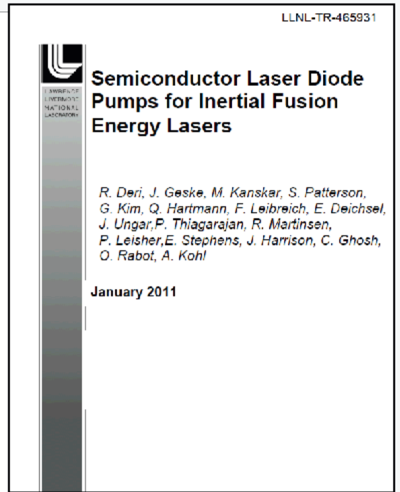
So, the required lasers almost exist.

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

Fiber Lasers

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]

10 J, 10 kHz

Some dreams of $\gamma\gamma$ factories at ILC

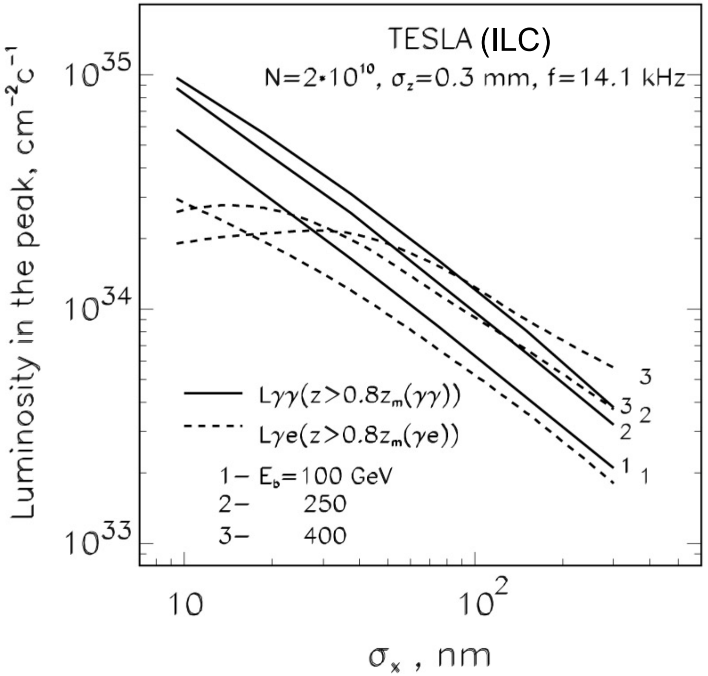
(PLC based on ILC, with very low emittances, without damping rings)

Factors limiting $\gamma\gamma,\gamma e$ 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 , $\beta_y \sim \sigma_z$

In $\gamma\gamma$ collsions the luminosity is limited only by available beam sizes or geometric e^-e^- luminosity (for at $2E_0$<1 TeV).

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!

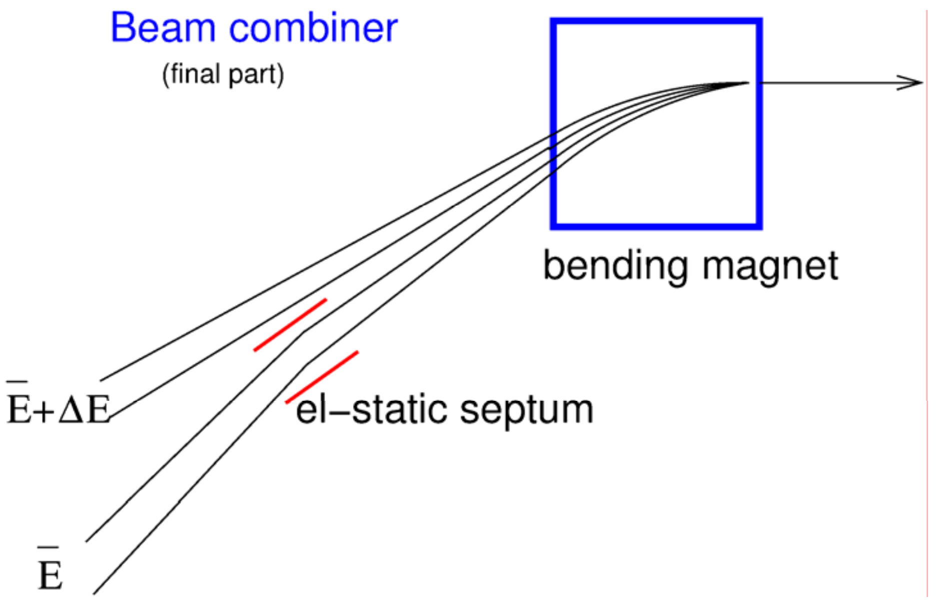
So, photoguns have much smaller longitudinal emittances than it is needed for linear collider (both e+e- or $\gamma\gamma$).

How can we use this fact?

A proposed method

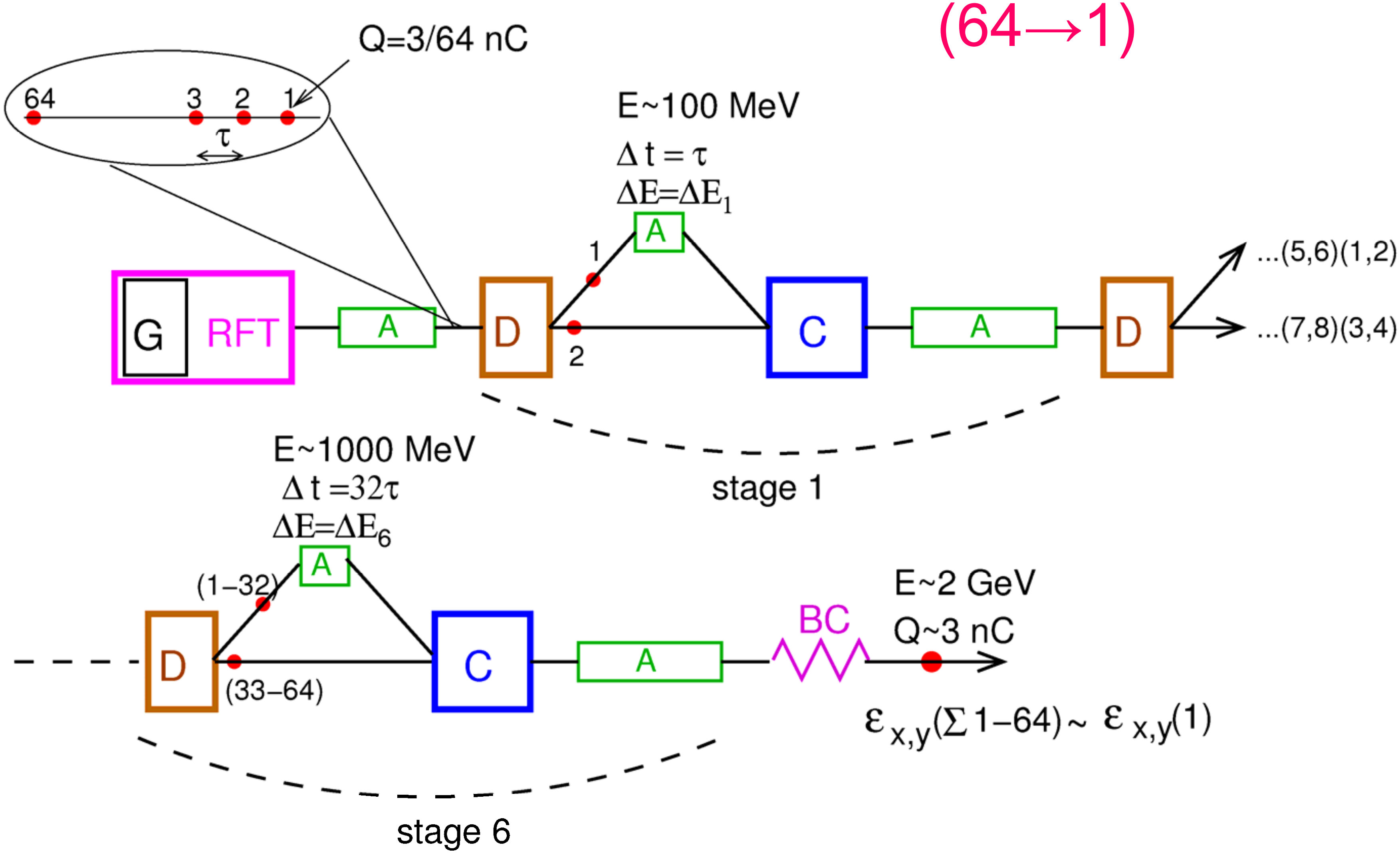
Let us combine many low charge, low emittance beams from photo-guns to one bunch using some differences in their energies. The longitudinal emittance increases approximately proportionally to the number of combined bunches while the transverse emittance (which is most important) remains almost constant.

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

$$L_{RFgun}/L_{DR}=\sim5\text{-}10$$

So, with polarized RF-guns one can get the luminosity ~5-10 times higher than with DR.

Polarized RF-guns still have emittances larger than that of unpolarized guns but there is good progress and soon we will have the required low emittance polarized guns.

Conclusion

- Photon colliders is a very cost effective addition for e+e- linear colliders: as the LC second stage or as the second IP (preferable). All required technologies exist.

- The ILC is close to approval. It is very important to make the final ILC design compatible with the photon collider and further develop the PLC as an integral part of the ILC project.