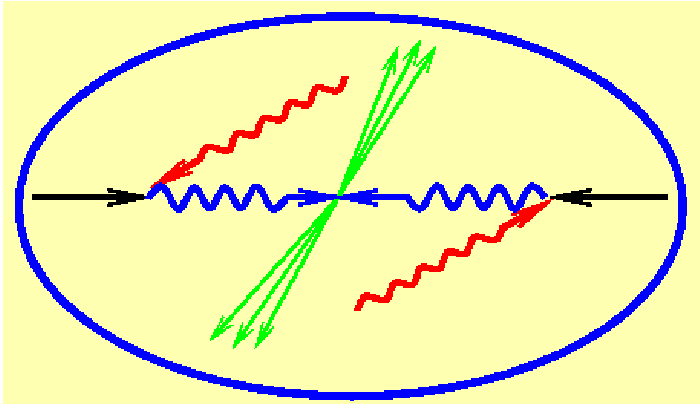

An idea of high energy γγ, γe collider based on one pass e+e- linear collider

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PHOTON 2015, June 16, 2015

Contents

- Introduction
- Idea of the high energy photon collider
- Basic principles and properties the $\gamma\gamma$, γe collider
- ILC
- CLIC
- SAPPHIRE, HFitt and others
- Super $\gamma\gamma$ factory
- Conclusion

Introduction

Physics in $\gamma^*\gamma^*$ is quite interesting, though it is difficult to compete with e^+e^- collisions because the number of equivalent photons is rather small and their spectrum soft

$$dn_\gamma \approx \frac{2\alpha}{\pi}\frac{dy}{y}\left(1-y+\frac{1}{2}y^2\right)\ln\frac{E}{m_e} \sim 0.035\,\frac{d\omega}{\omega}; \qquad y=\frac{\omega}{E}$$

$L_{\gamma\gamma}(z>0.1) \sim 10^{-2}\, L_{e+e-}$

$z=W_{\gamma\gamma}/2E_0$

$L_{\gamma\gamma}(z>0.5) \sim 0.4 \bullet 10^{-3}\, L_{e+e-}$

Idea of the photon collider

In December 1980 at the First workshop on physics at the linear collider VLEPP in Novosibirsk it was suggested (V.T. and colleagues) to convert electrons to real photons in order to increase the $\gamma\gamma$ luminosity.

The idea is based on the fact that at linear colliders electron beams are used only once which makes possible to convert electron beam to high energy photons just before the interaction point (it is not possible at storage ring).

The conversion can be done in the best way using Compton scattering of the laser light off the high energy electrons in the linear collider.

$$E_\gamma \sim E_e \; ; \quad L_{\gamma\gamma} \sim L_{e+e-}$$

In Feb.1981-83 we published a short paper and then two thick papers of the photon colliders:

1. I.Ginzburg, G.Kotkin, V.Serbo, V.Telnov, On posibility of obtaining gamma-gamma, gamma-electron beams with high energy and luminosity, Preprint INP 81-50, Feb.1981, Pizma ZhETF 34 (1981) 514; JETP Lett. 34 (1982) 91;

2. I.Ginzburg, G.Kotkin, V.Serbo, V.Telnov, Nucl.Insr.and Meth 205 (1983) 47;

3. I.Ginzburg, G.Kotkin, S.Panfil, V.Serbo, V.Telnov, Nucl.Insr.&Meth A219 (1984) 5;

Note, the first paper was not accepted to ZhETF (twice) and Phys.Lett, it was accepted to ZhETF only after direct talk with the editor. Now these papers have citation indices: ~230, 670, 570.

Methods of e$\to\gamma$ conversion

The simplest method is bremsstrahlung in a amorphous (or crystal) target:

$$dn_\gamma \sim \frac{x}{X_0}\frac{d\omega}{\omega}$$

If $x/X_0 = 0.3$, the number of photons is 10 times larger than the number of virtual photons and the $\gamma\gamma$ luminosity is 100 times larger than in $\gamma^*\gamma^*$. Problems: ph. nucl. backgrounds, damage of the target.

The best method is the Compton scattering of laser light off high energy electrons. This method was known since 1964 (Arutyunian, Tumanian, Milburn) and was used since 1966 at SLAC and other labs with $k=n_\gamma/n_e \sim 10^{-6}$.

We estimated that k~1 is realistic due to small beam sizes at linear collider. The required laser flash energy is about 1-10 J.

Initial scheme of the photon collider

1981

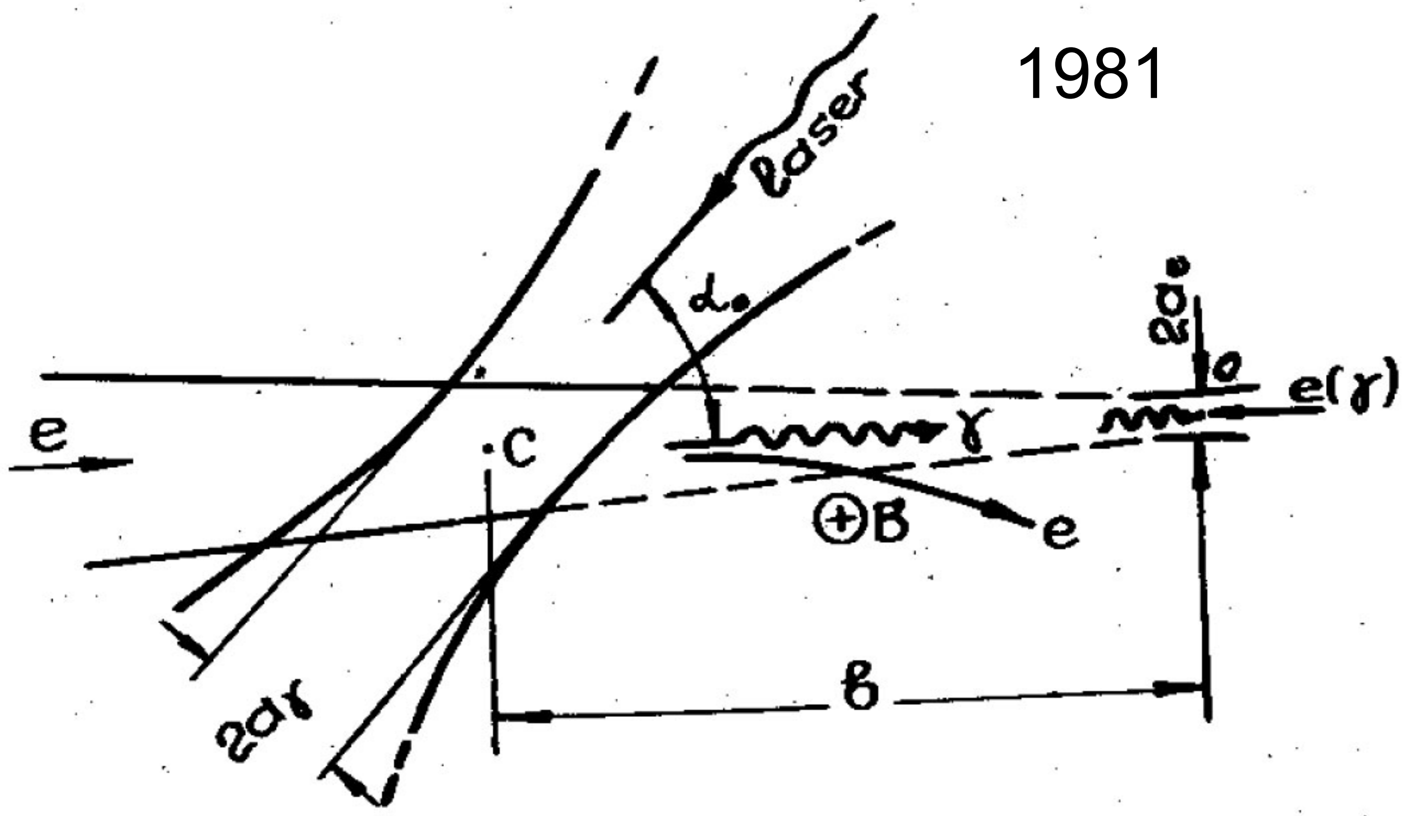
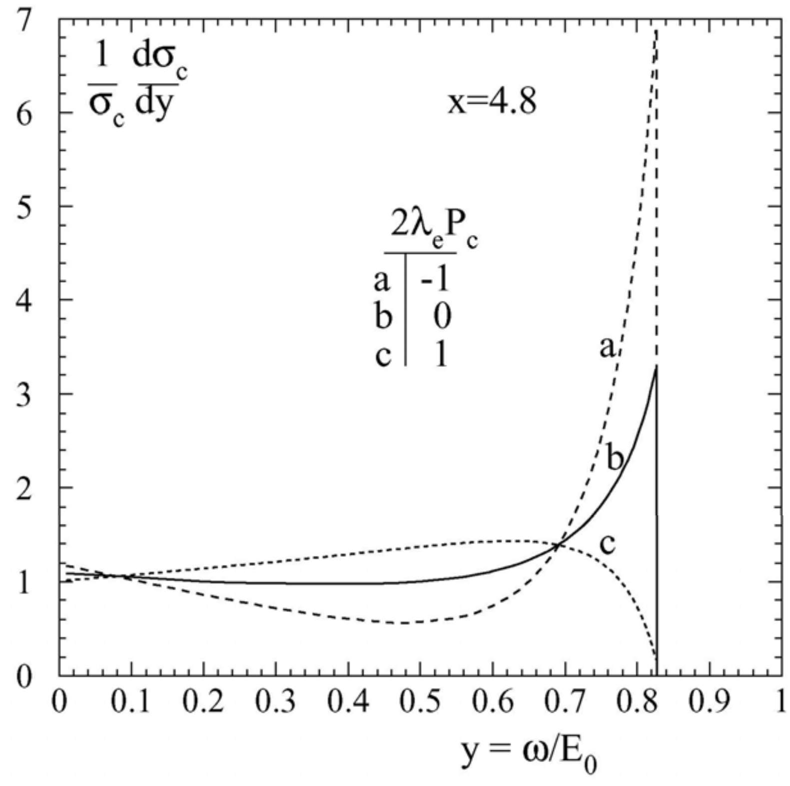


Fig.1. Scheme of obtaining of the colliding γe – and $\gamma\gamma$ – beams.

Electron to Photon Conversion

Spectrum of the Compton scattered photons

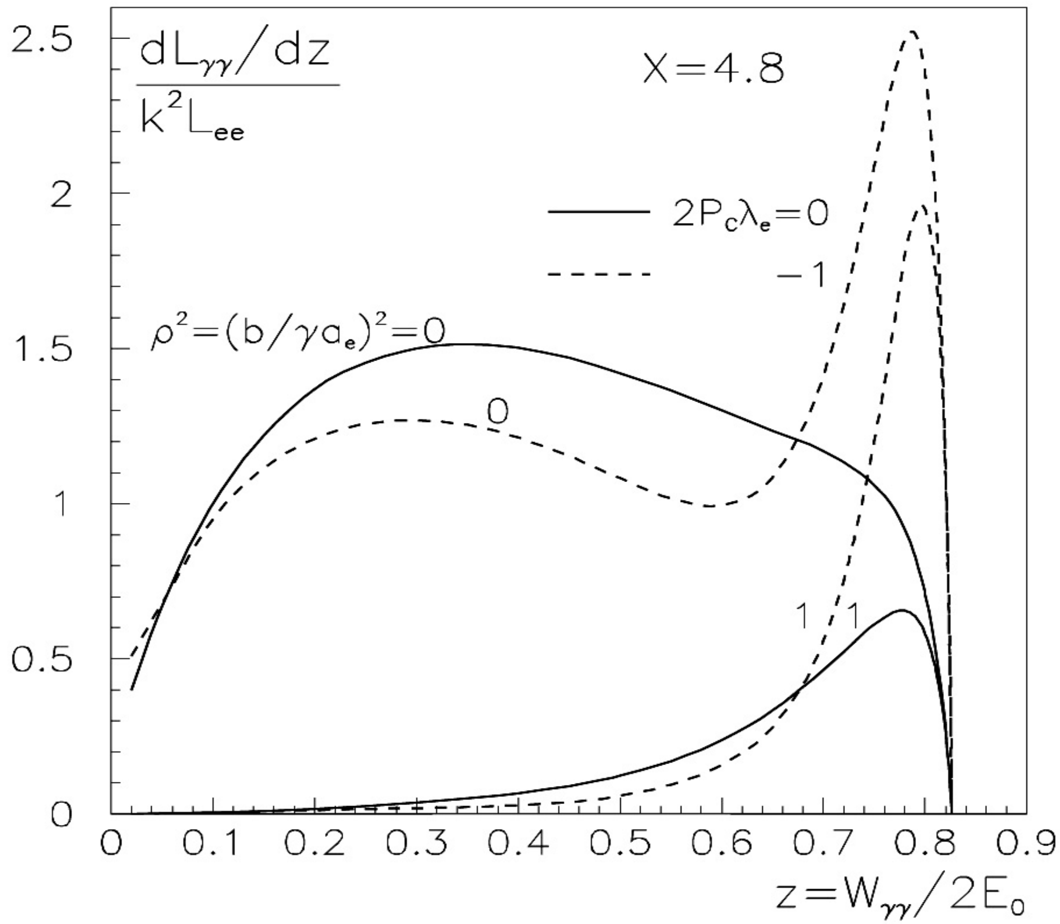


λ_e – electron longitudinal polarization
P_c – helicity of laser photons, $x \approx \frac{4E_0\omega_0}{m^2c^4}$

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

Ideal luminosity distributions, monohromatization

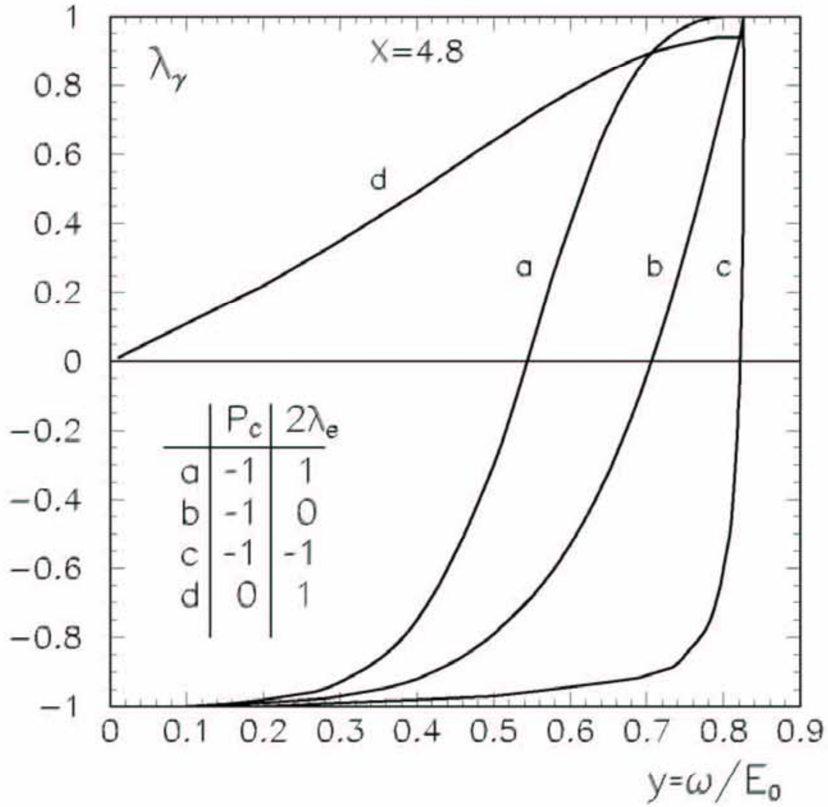
(a_e is the radius of the electron beam at the IP, b is the CP-IP distance)



At b/γ larger than the minimum transverse electron size the high energy photons collide at smaller spot size and give larger contribution to the luminosity spectrum than low energy photons which leads to monochromatization" of γγ collisions. In figure, photons from multiple Compton scattering and beamstrahlung are not taken into account (see realistic spectra in page ?).

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 ($x = 4.8$)



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

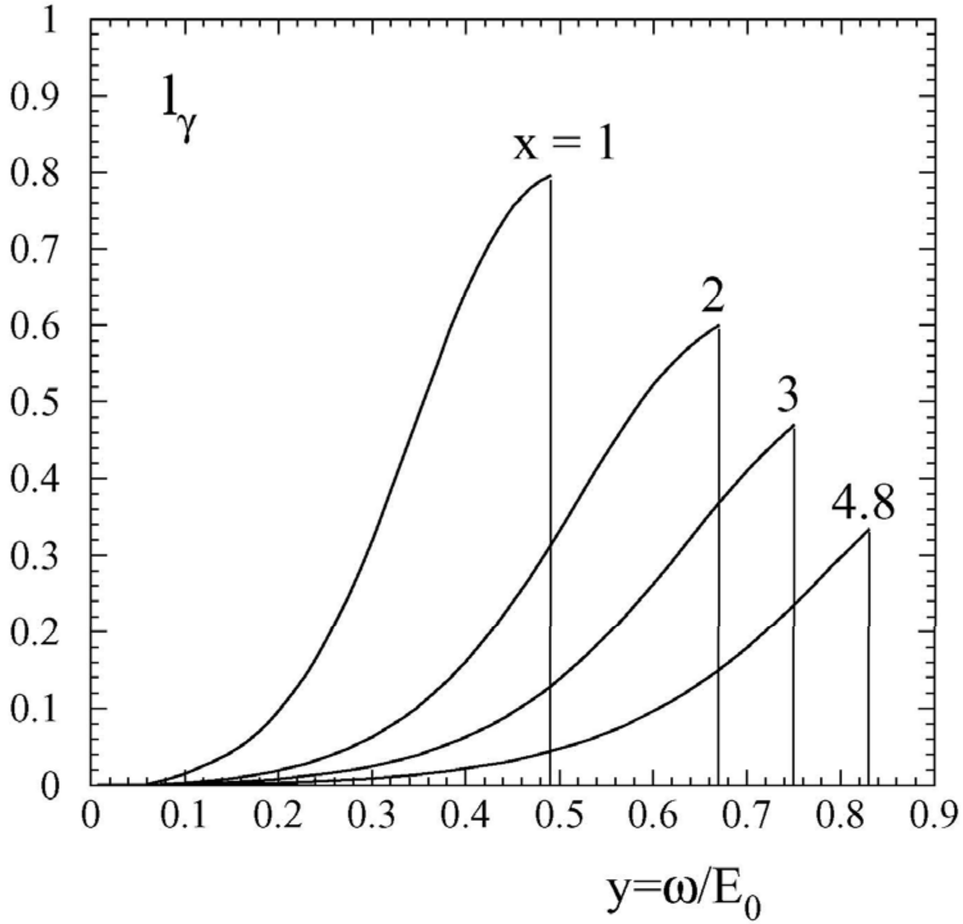
The cross section of the Higgs production

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

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 allows to measure Higgs CP mixture and helps to separate SUSY H and A Higgs bosons

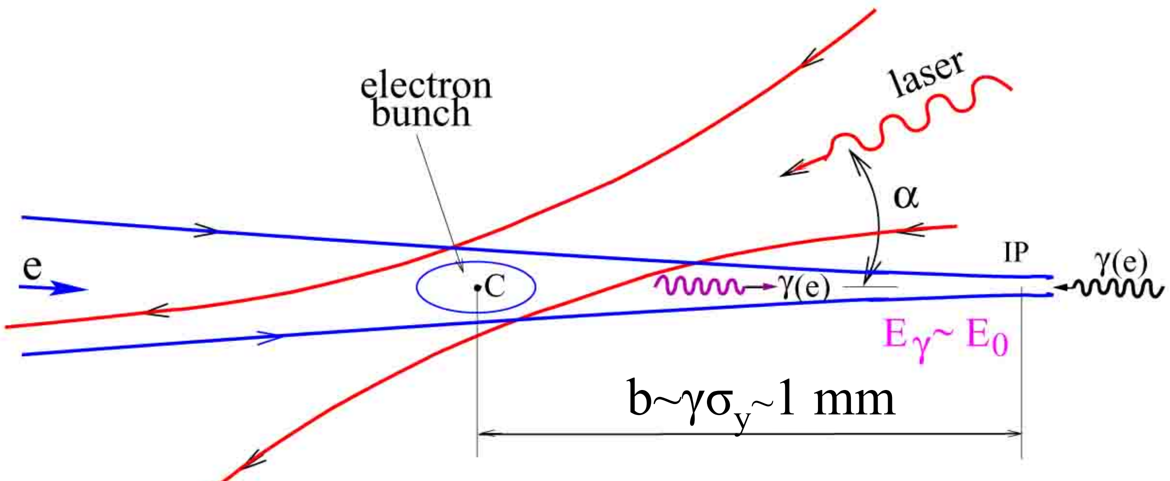
Main technical problems of photon colliders

1) Removal of used beams with wide energy and angular spread from the detector
2) Powerful lasers, with A~10 J, $\tau \sim 1$ ps, rep. rate 10 kHz
3) Optimum collision scheme, collision effects, backgrounds

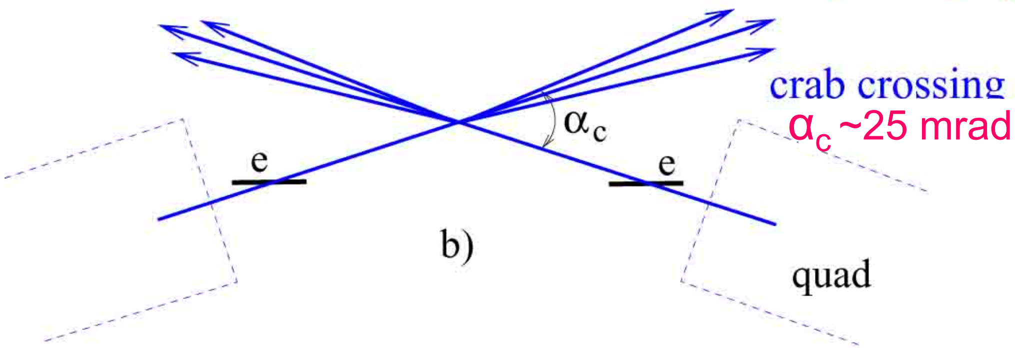
Solutions for most of these problems were given in
V.I. Telnov, Problems of Obtaining γγ and γe Colliding Beams at Linear Colliders, Nucl.Instrum.Meth, A294 (1990) 72-92

S. Chattopadhyay, AIP Conference Proceedings **335**, 190 (1995):
"The physics of gamma-gamma collisions and its potential utility was exposed in a series of pioneering articles by Ginzburg, et al. (1) slightly more than a decade ago. Sporadic articles appeared in the literature throughout the 1980's culminating in a detailed exposition of a possible gamma-gamma collider scenario by Telnov (2) in 1990"

Scheme of $\gamma\gamma$, γe collider



a)



b)

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

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

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

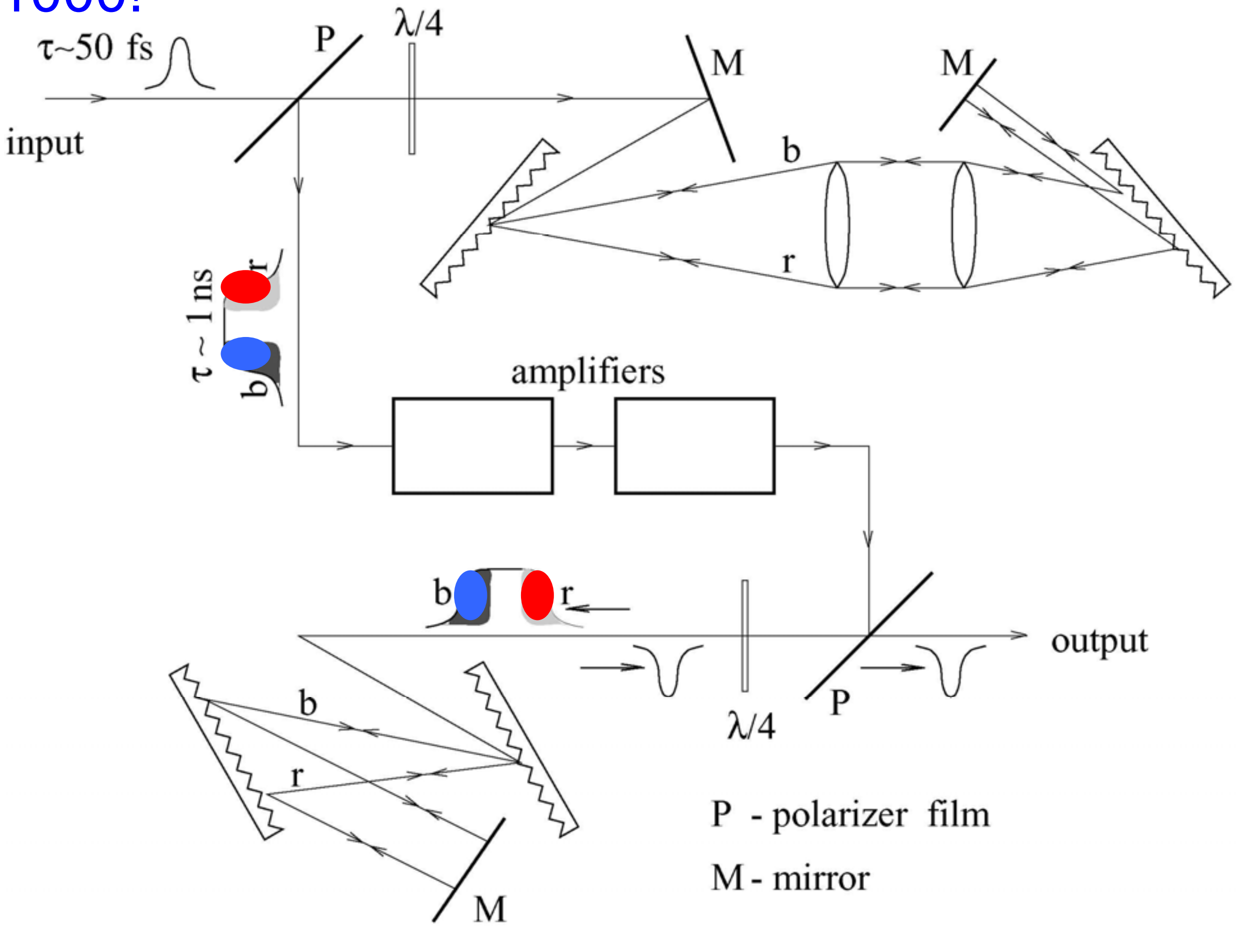
$x = 4.8$ is the threshold for
$\gamma\gamma_L \to e^+e^-$ at conv. reg.

ω_{max}~0.8 E_0

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

Chirped pulse laser technique invented in 1985 was revolutionary and made photon colliders really feasible

Stretching-amplification-compression allows to avoid nonlinear effects (self-focusing) during amplification and thus to increase laser a power by a factor of 1000!



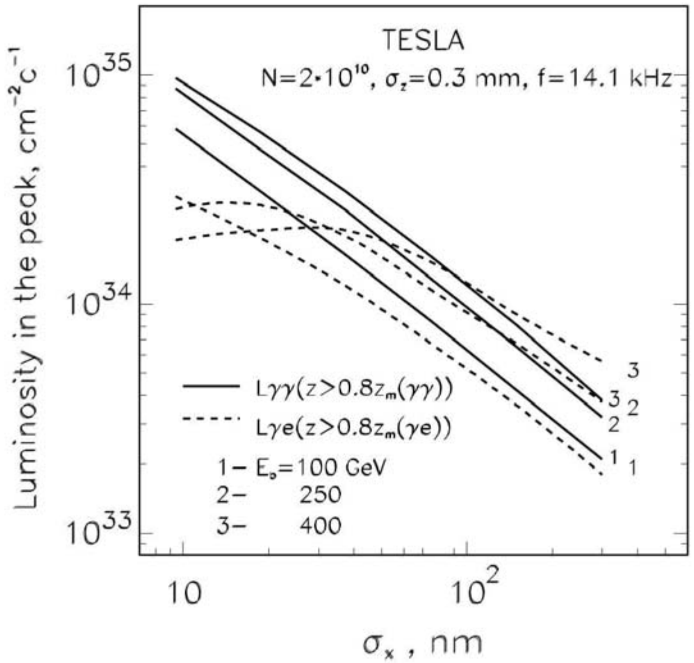
Other technologies important for the photon collider: diode pumping, adaptive optics, high reflective multilayer mirrors for high powers – all is available now.

Factors limitting $\gamma\gamma$,γe luminosities

Collisions effects:

- Coherent pair creation
- Beamstrahlung
- Beam-beam repulsion
- Depolarization (not important)

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



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

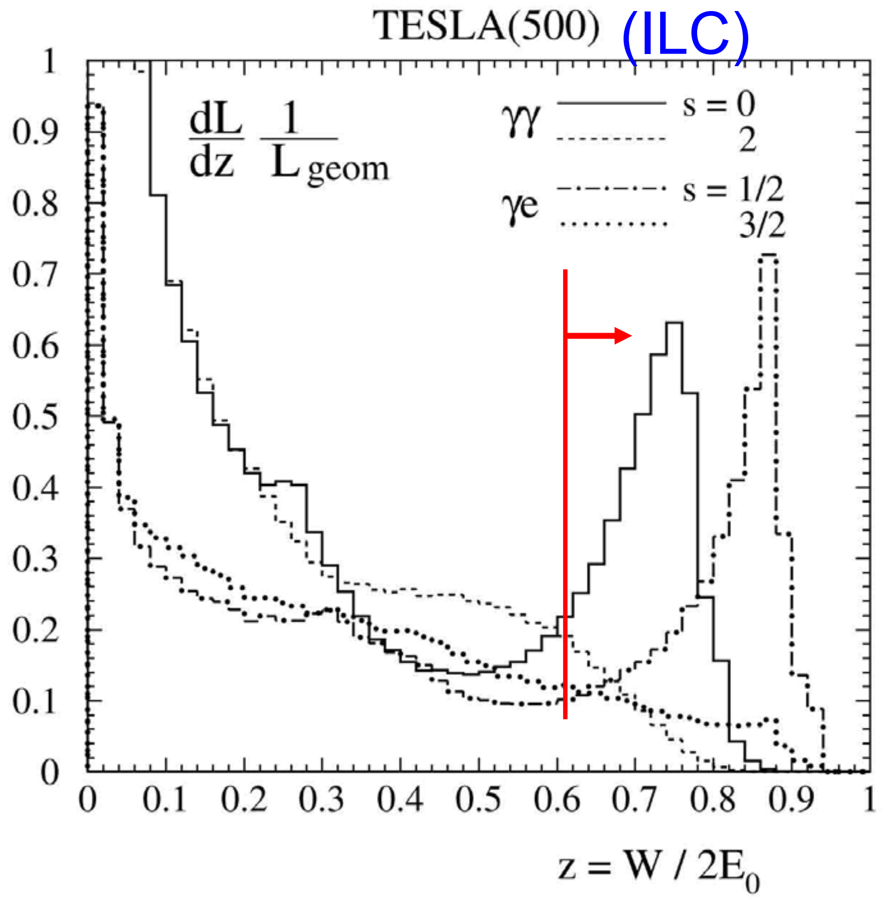
γe luminosity in the high energy peak is limited due to the beam repulsion and beamstrahlung

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

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, $z>0.8z_m$.

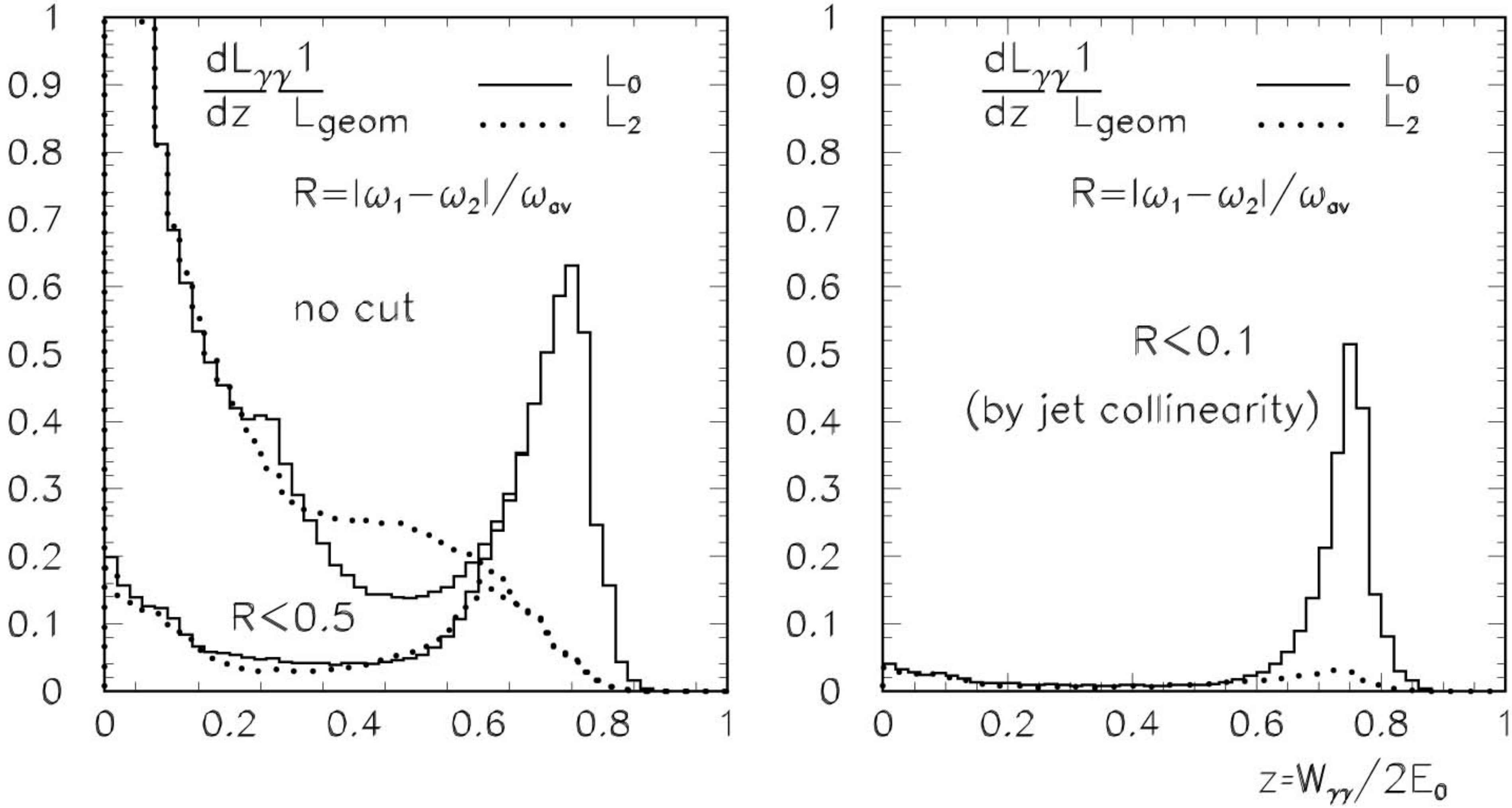
For ILC conditions

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

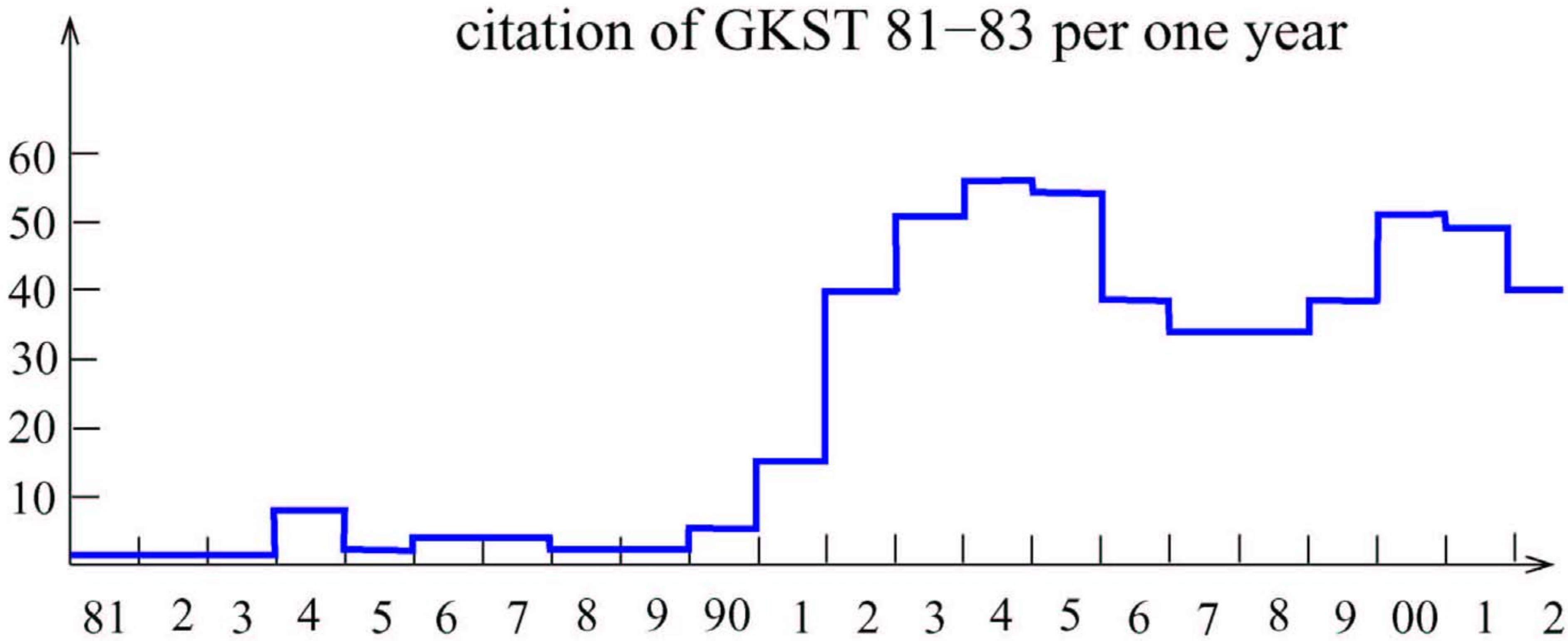
(but cross sections in $\gamma\gamma$ are larger than in e+e- by one order!)

In 1993 the simulation code was developed (V.I.T) for simulation of photon collides, which included all important effects.

$\gamma\gamma$ luminosity spectra with cuts on the longitudinal momentum



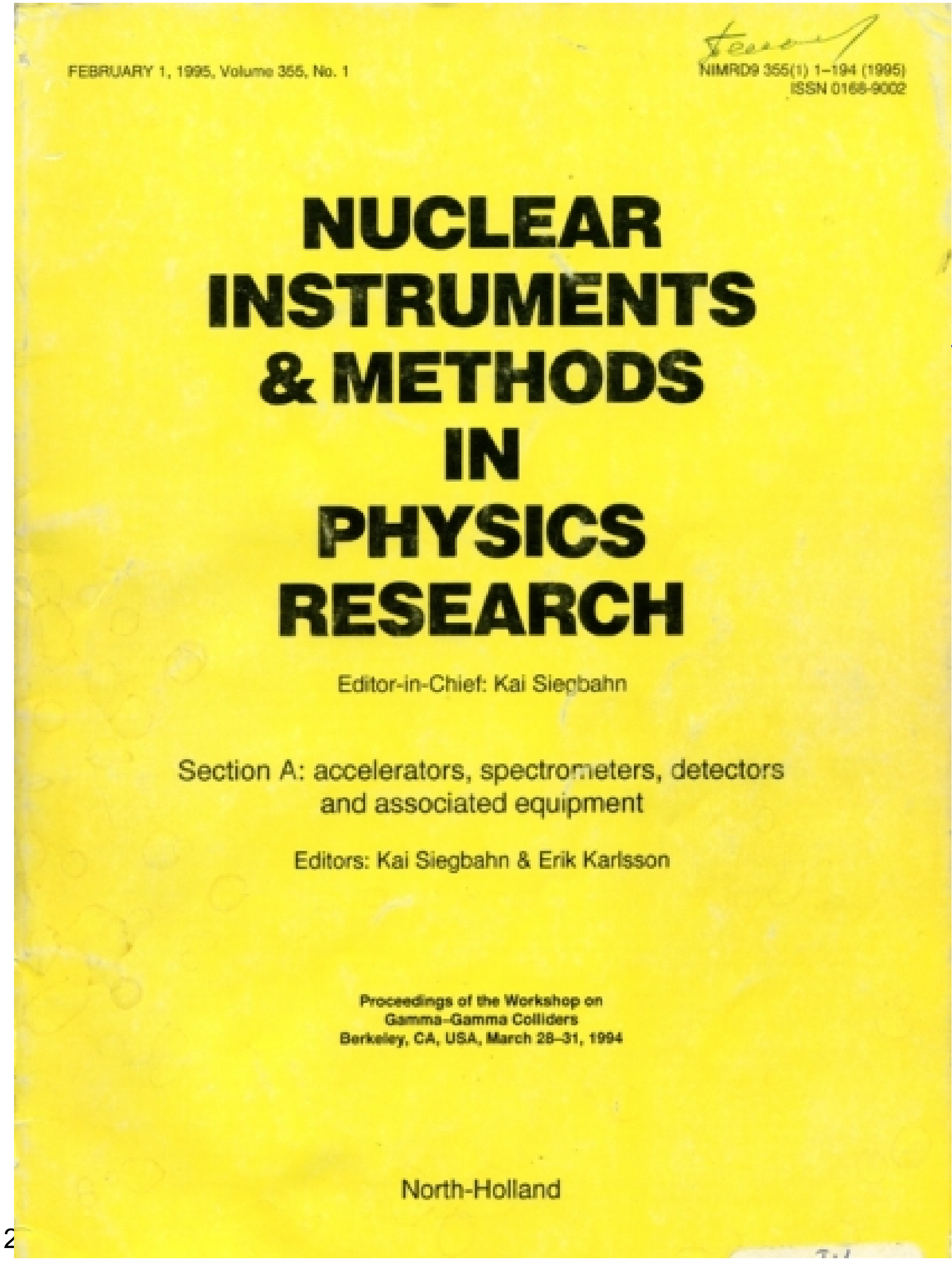
Activity on photon colliders



(total number of publications is larger by a factor of 2)

→ about 2 papers/week

Dedicated Gamma-gamma collider workshops and proposals


FEBRUARY 1, 1995, Volume 355, No. 1

NIMRD9 355(1) 1–194 (1995)
ISSN 0168-9002

NUCLEAR
INSTRUMENTS
& METHODS
IN
PHYSICS
RESEARCH

Editor-in-Chief: Kai Siegbahn

Section A: accelerators, spectrometers, detectors
and associated equipment

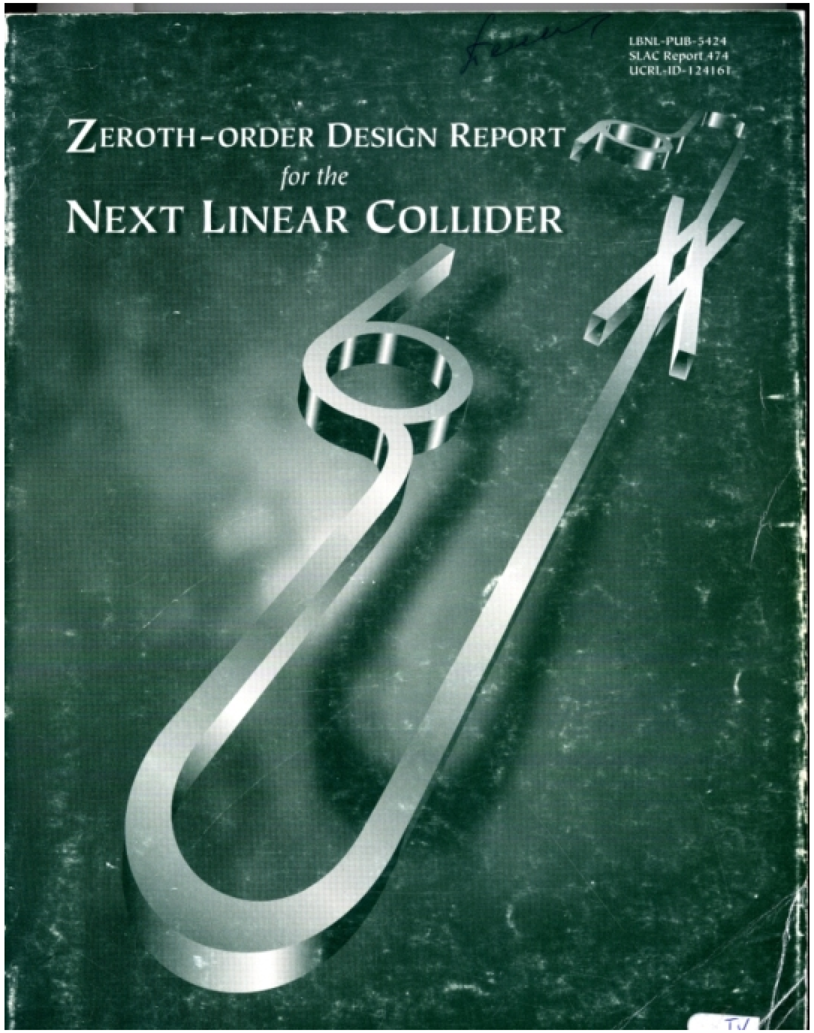
Editors: Kai Siegbahn & Erik Karlsson

Proceedings of the Workshop on
Gamma-Gamma Colliders
Berkeley, CA, USA, March 28–31, 1994

North-Holland

Gamma-gamma workshop
LBL, 1994
32 papers

Gamma-gamma in NLC ZDR (1996)



B

A Second Interaction Region For Gamma-Gamma, Gamma-Electron and Electron-Electron Collisions

Contents

Contributors

- Karl van Bibber
- Swapan Chattopadhyay
- Bill Fawley
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- Tim Houck
- John Irwin
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- Andy Sessler
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- Valery Telnov
- Achim Weidemann
- Glen Westenskow
- Ming Xie
- Kaoru Yokoya
- Sasha Zholents

TESLA CDR (1997)

A Second Interaction Region For Gamma-Gamma and Gamma-Electron collisions

R. Brinkmann[1], I. Ginzburg[2], N. Holtkamp[1], G. Jikia[3], O. Napoly[4], E. Saldin[5], E. Schneidmiller[5], V. Serbo[6], G. Silvestrov[7], V. Telnov[7] (Editor), A. Undrus[7], M. Yurkov[8]

Nucl.Instrum.Meth. A406 (1998) 13-49

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8) JINR, Dubna

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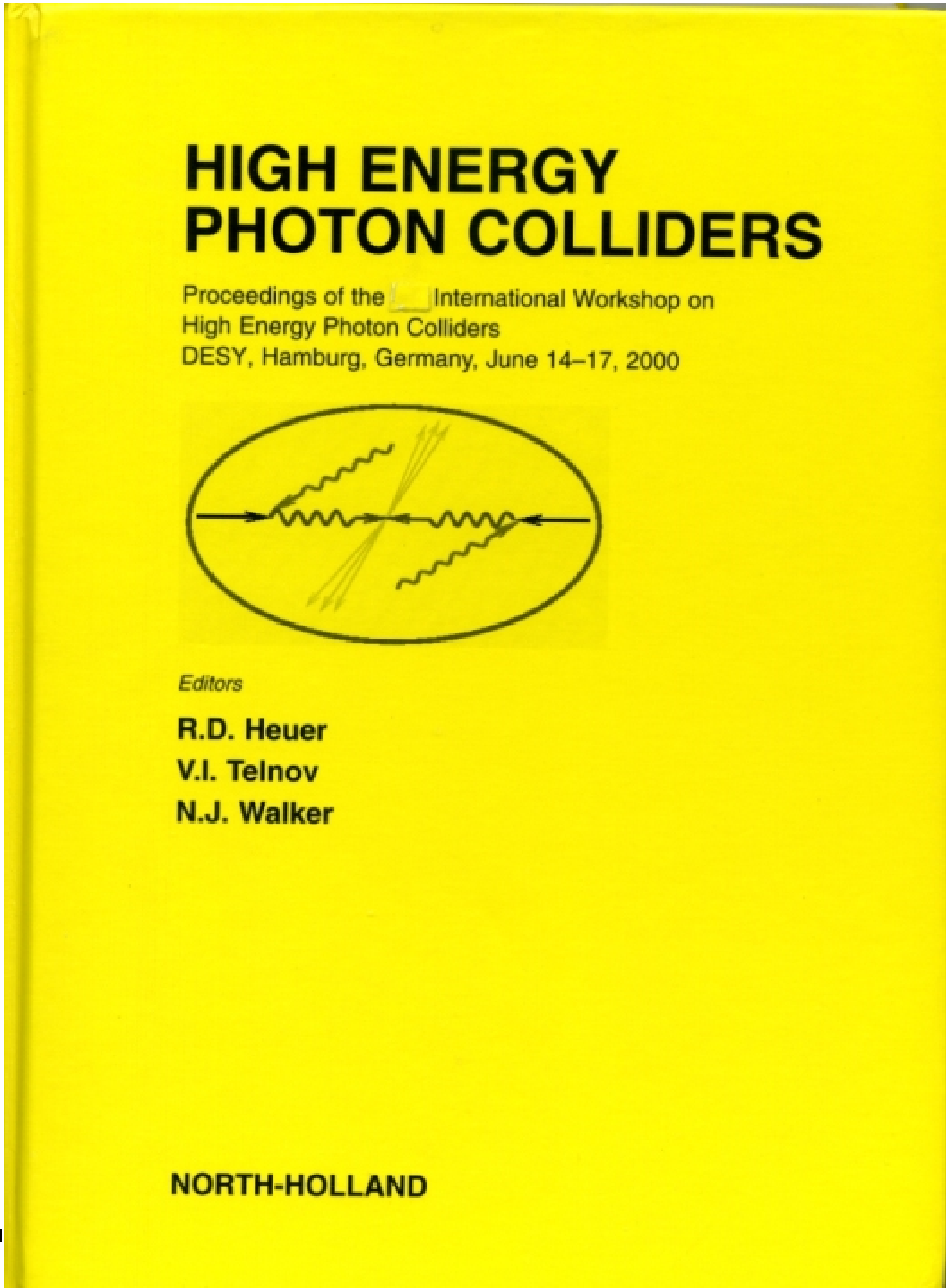
A/H

$\gamma\gamma$ Collider as an Option of JLC

I. WATANABE, S. HIRAMATSU, K. NAKAJIMA, T. TAUCHI, K. YOKOYA,
I. ENDO, K. MATSUKADO, T. OHGAKI, T. TAKAHASHI, I. ITO, T. KON,
N. MATSUDA and T. TAKESHITA

High Energy Accelerator Research Organization

$\gamma\gamma$ at JLC, 1997


HIGH ENERGY PHOTON COLLIDERS

Proceedings of the International Workshop on
High Energy Photon Colliders
DESY, Hamburg, Germany, June 14–17, 2000

Editors

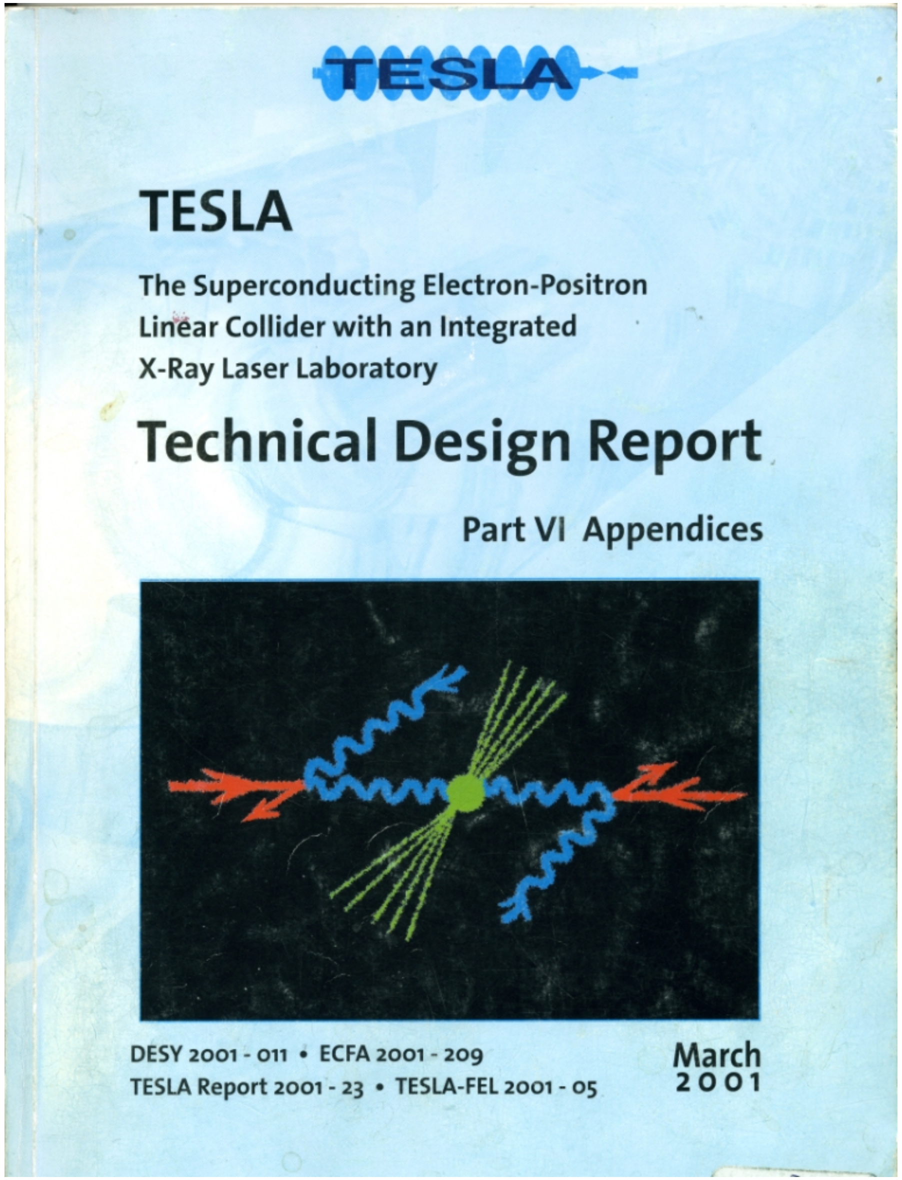
R.D. Heuer
V.I. Telnov
N.J. Walker

NORTH-HOLLAND

Workshop at DESY (2000)

45 talks

TESLA TDR: Photon collider



2001

1 The Photon Collider at TESLA

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[20], 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].

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[44] Universität Würzburg, Germany

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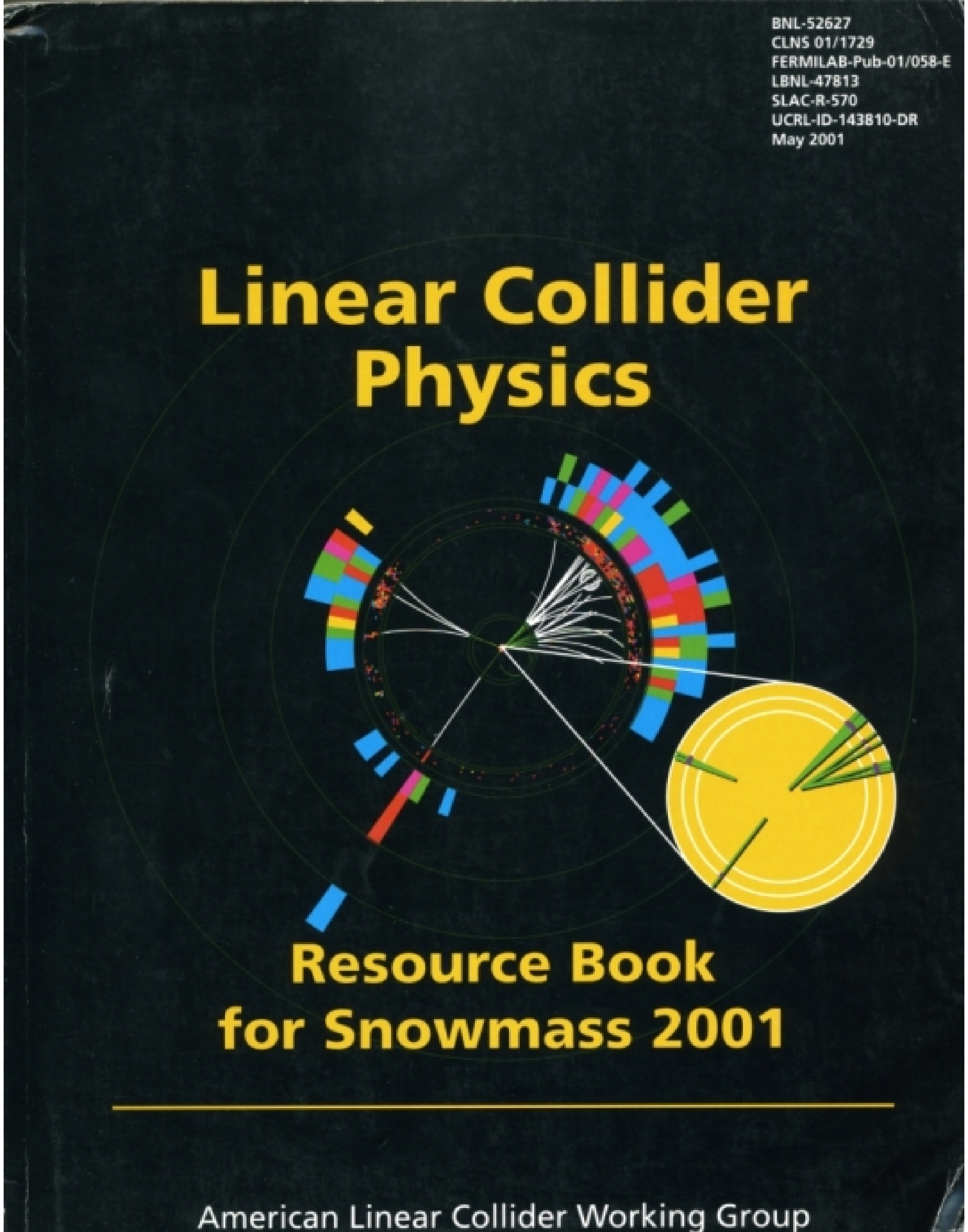
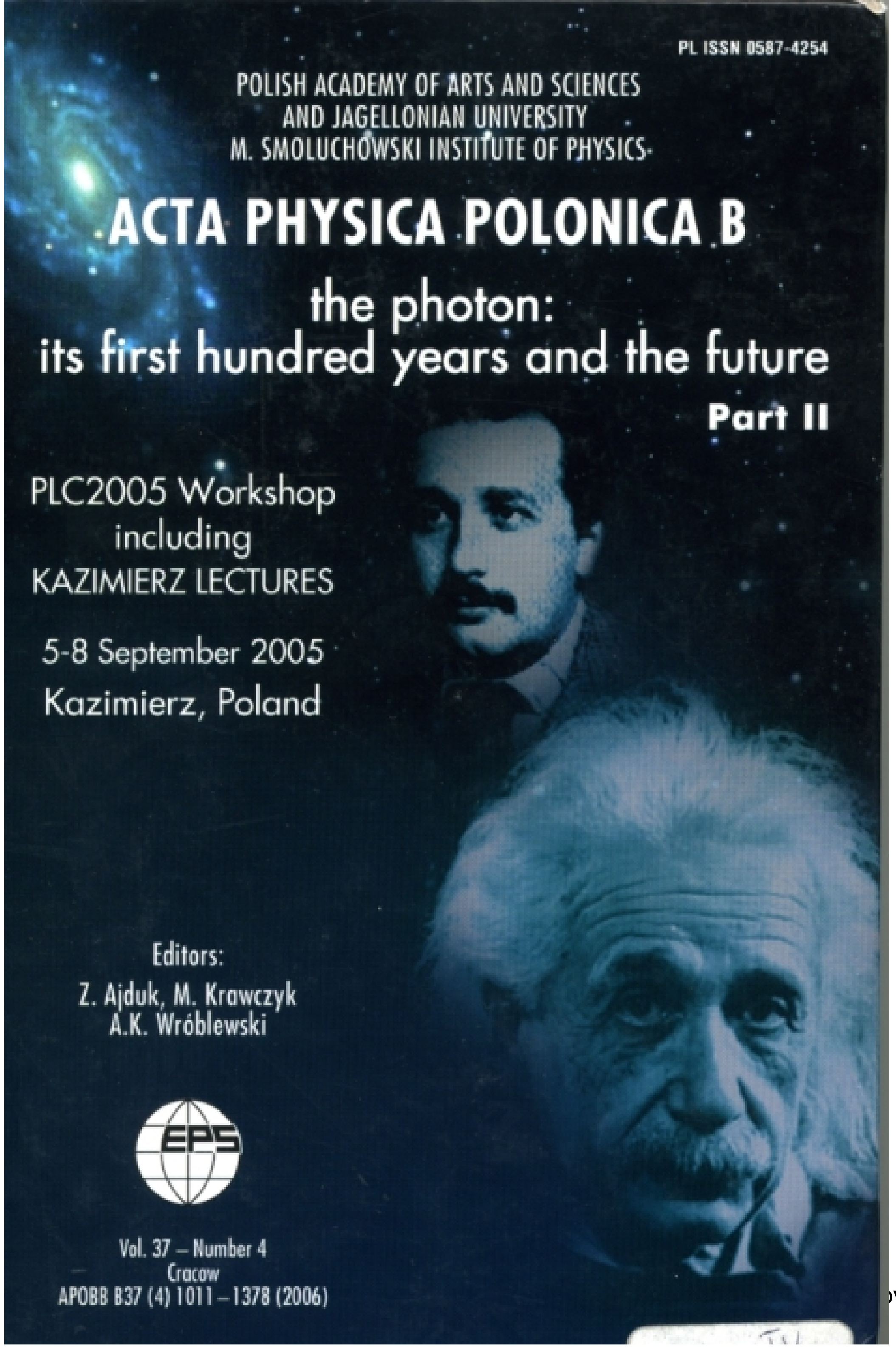


USA
Snowmass 2001

Chapter on photon-collider



Workshop:
Photon Linear colliders 2005

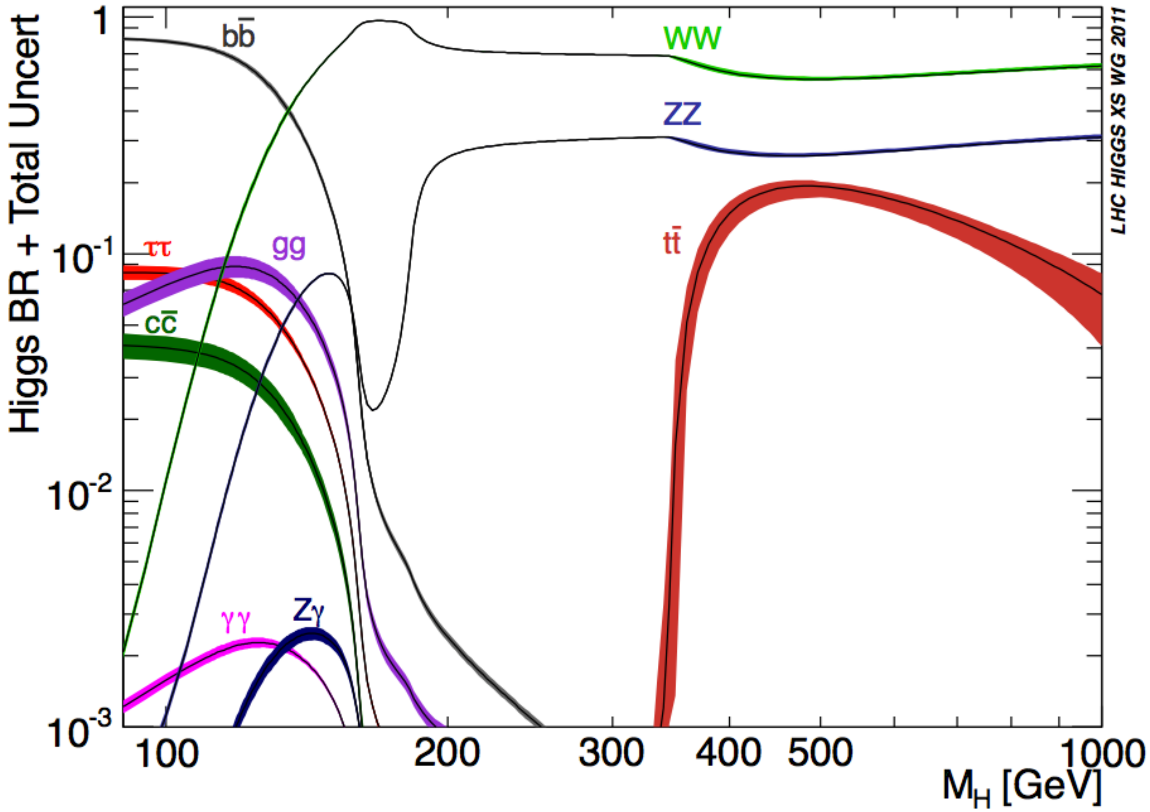
he also supports
photon colliders

Physics at PLC

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

By now, only the light (standard) Higgs boson is discover.

Higgs decay branchings

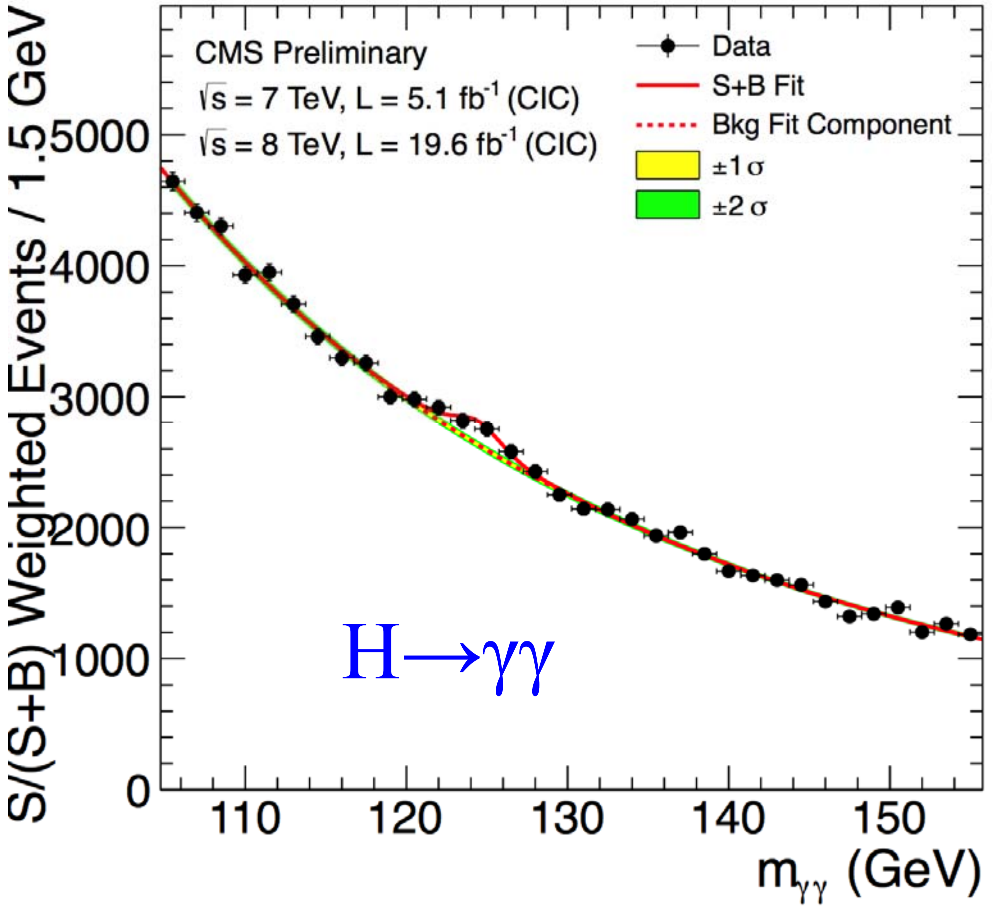


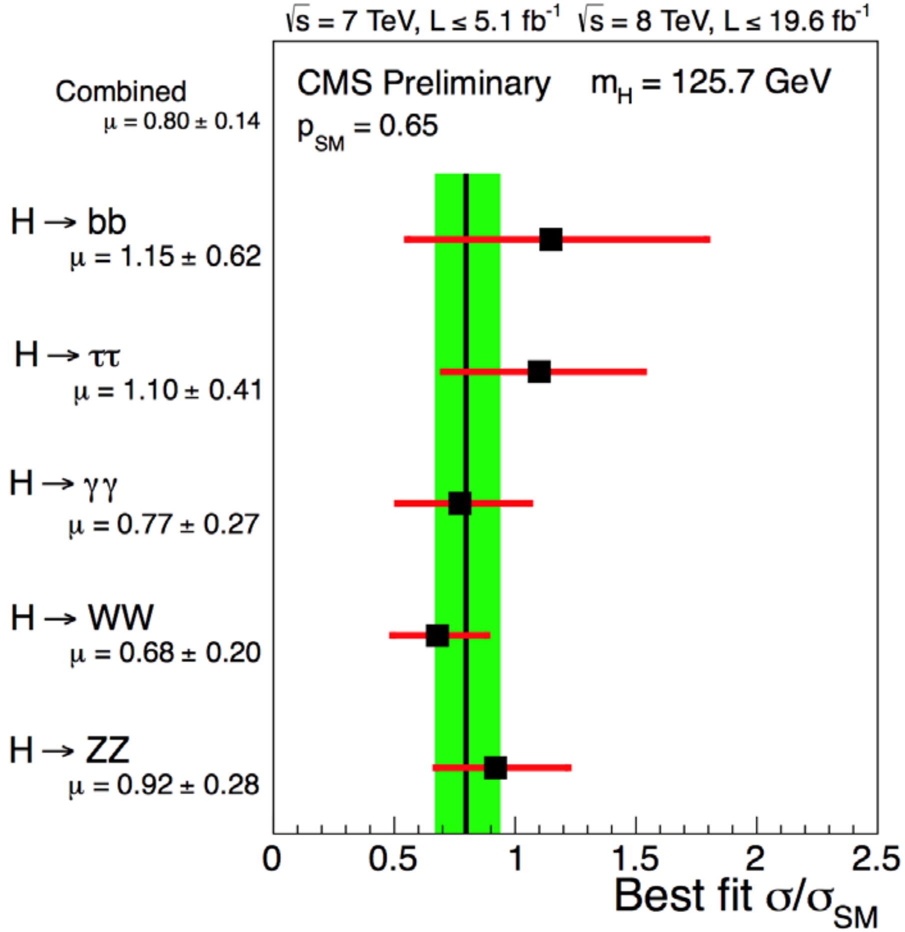
SM predictions (m_H = 125.5 GeV):

BR (H→ WW) = 22.3%	BR (H → bb) = 56.9%
BR (H → ZZ) = 2.8%	BR (H → $\tau\tau$) = 6.2%
BR (H → $\gamma\gamma$) = 0.24%	BR (H →$\mu\mu$) = 0.022%

→ at 125 GeV: only ~11% of decays not observable (gg, cc)

Higgs to $\gamma\gamma$ at CMS

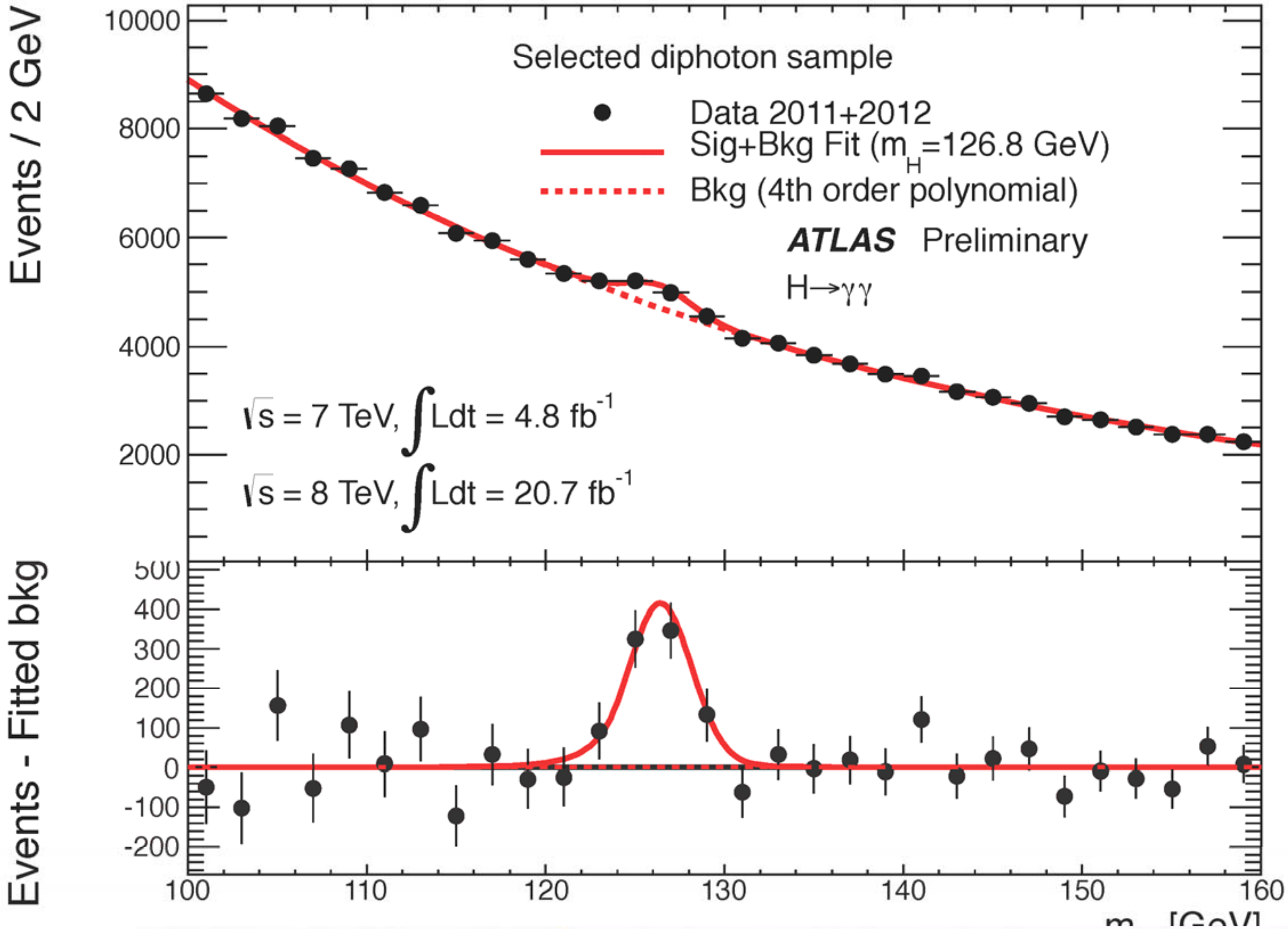




$\mu(\text{for } \gamma\gamma) \equiv \sigma/\sigma_{SM} = 0.77 \pm 0.27$

Higgs to γγ at ATLAS

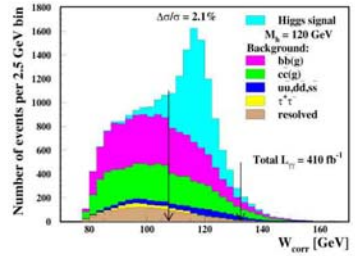
Full dataset ATLAS-CONF-2013-012



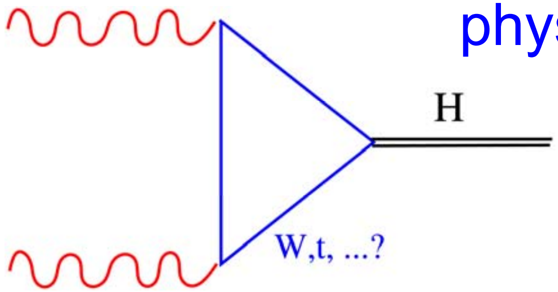
Mass: $m_H = 126.8 \pm 0.2\,(\text{stat}) \pm 0.7\,(\text{syst})$ GeV

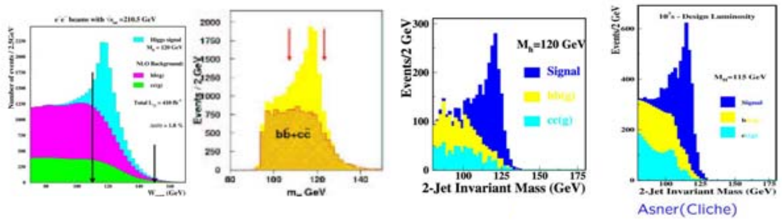
Signal strength: (m_H = 126.8 GeV) $\mu := \sigma / \sigma_{SM} = 1.57 \pm 0.22(\text{stat})\,^{+0.24}_{-0.18}(\text{syst})$

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



This process is most sensitive to a new physics (high mass particles in the loop)





$$\dot{N}_H = L_{ee} \times \frac{dL_{0,\gamma\gamma}}{dW_{\gamma\gamma} L_{ee}} \frac{4\pi^2 \Gamma_{\gamma\gamma}}{M_H^2} (1 + \lambda_1\lambda_2 + CP * l_1 l_2 cos2\varphi) = L_{ee}\sigma$$

$$\sigma = \frac{0.98 \cdot 10^{-35}}{2E_0[\mathrm{GeV}]} \frac{dL_{0,\gamma\gamma}}{dz L_{ee}} (1 + \lambda_1\lambda_2 + CP * l_1 l_2 cos2\varphi), \ \mathrm{cm}$$

For realistic ILC conditions $\sigma(\gamma\gamma \to H) \approx 75$ fb (in terms of L_{ee}),

while $\sigma(e^+e^- \to HZ) \approx 290$ fb

in e+e- $N(H \to \gamma\gamma) \propto \sigma(e^+e^- \to HZ) * Br(H \to \gamma\gamma) L$, where $Br(H \to \gamma\gamma) = 0.0024$

in $\gamma\gamma$ $N(H \to \gamma\gamma) \propto \sigma(\gamma\gamma \to H) * Br(H \to bb) L$, where $Br(H \to bb) = 0.57$

Conclusion: in γγ collisions the $\Gamma(H \to \gamma\gamma)$ width can be measured with statistics (75*0.57)/(290*0.0024) ≈ 60 times higher than in e+e- collisions.

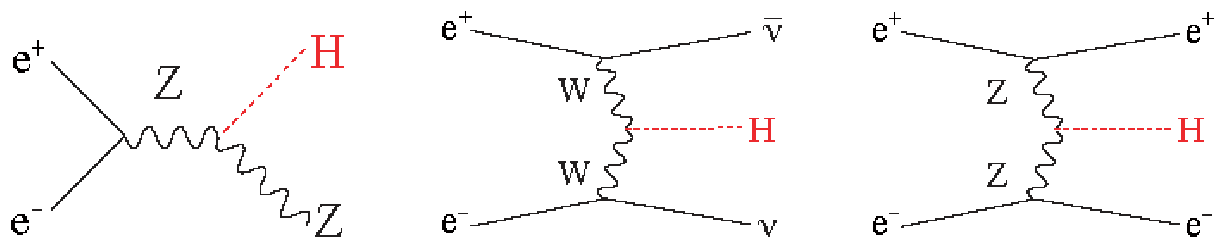
This is one of most important argument for the photon collider (for Higgs study).

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-(accuracy about 1%). As result the accuracy of $\Gamma(H\to\gamma\gamma)$ is about 1.5-2% after one years of operation. PC can not measure cc, $\tau\tau$, $\mu\mu$ due to large QED background.

e+e- can also measure $Br(bb, cc, gg, \tau\tau, \mu\mu, \text{invisible})$, Γ_{tot}, less backgrounds due to tagging of Z.



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

Measurement of the Higgs CP-properties

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

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.

Varying initial state photon polarizations one can measure the Higgs CP value with 5-10% accuracy after one year of operation.

(In e+e- collisons CP-violation can be measured only using particle correlations in final states)

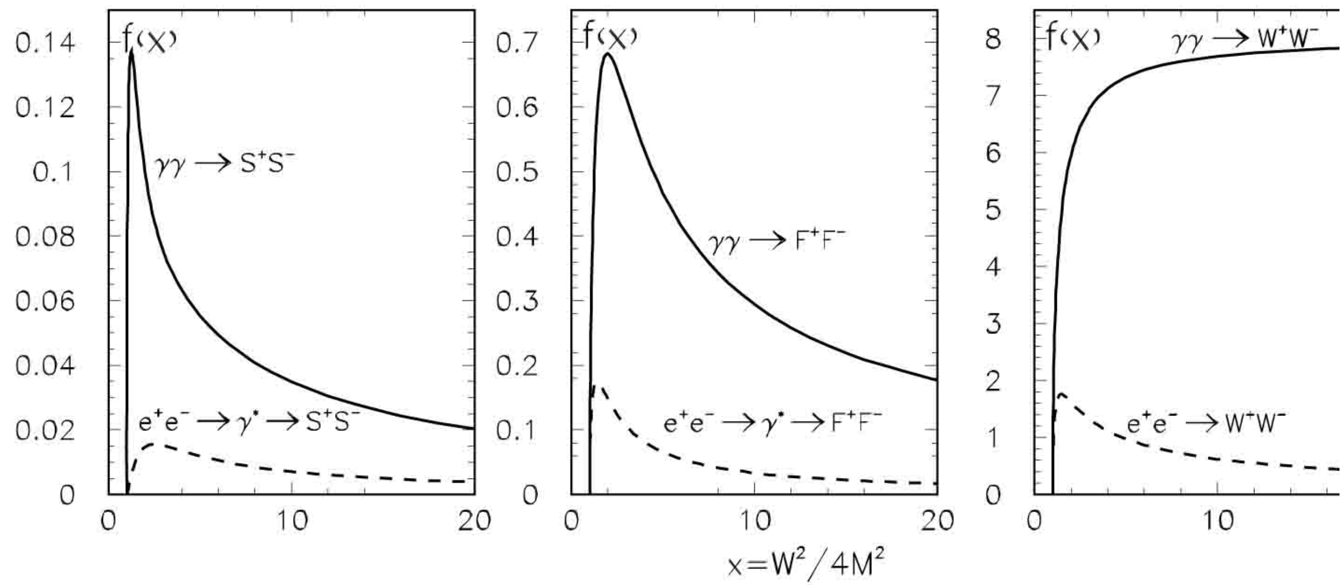
Some examples of Physics (in addition to H(125))

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

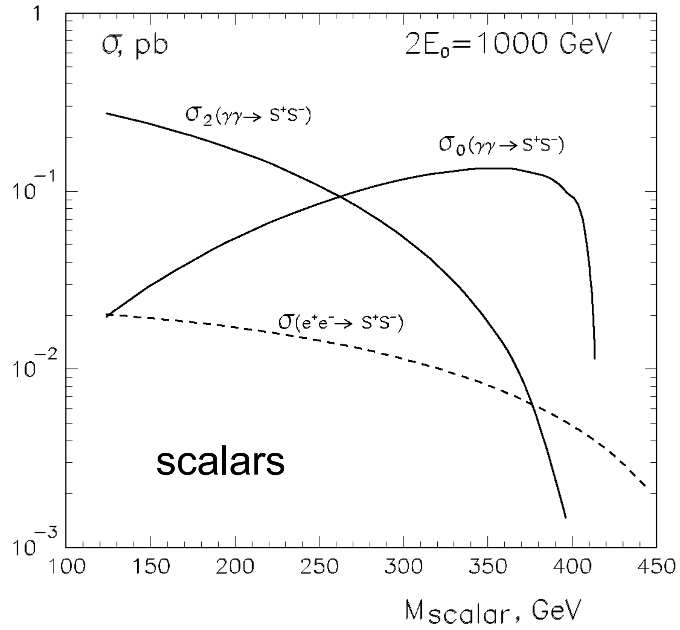
unpolarized beams

(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:

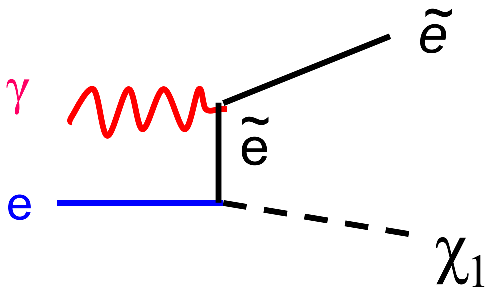
in e$^+$e$^-$ collisions $M_{H,A}^{max} \sim E_0$ (e$^+$e$^-$ $\to H + A$)
in $\gamma\gamma$ collisions $M_{H,A}^{max} \sim 1.6 E_0$ ($\gamma\gamma \to H(A)$)

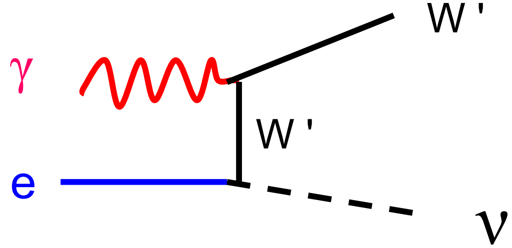
For some SUSY parameters H,A can be seen only in $\gamma\gamma$
(but not in e+e- and LHC)

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):

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





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 an unique case when the same collider allows to study new physics in several types of collisions at the cost of rather small additional investments

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. Recently LLNL started work on LIFE lasers for thermonuclear plant which seems very attractive (one pass laser). Further developments need political decisions and finances.

Crossing angle

At present it is important to make the ILC design compatible with the photon collider.

Now for e+e- the crossing angle α_c=14 mrad

For photon collider one needs α_c~25 mrad (because larger disruption angles)

Dependence of $L_{\gamma\gamma}$ on α_c:

25 mrad	1
23 mrad	~0.76
20 mrad	~0.43
14 mrad	~0

CLIC needs 20 mrad.

So, the ILC team should change α_c=14 to 23-25 mrad in order to have in future the possibility of CLIC and PLC in the same tunnel !

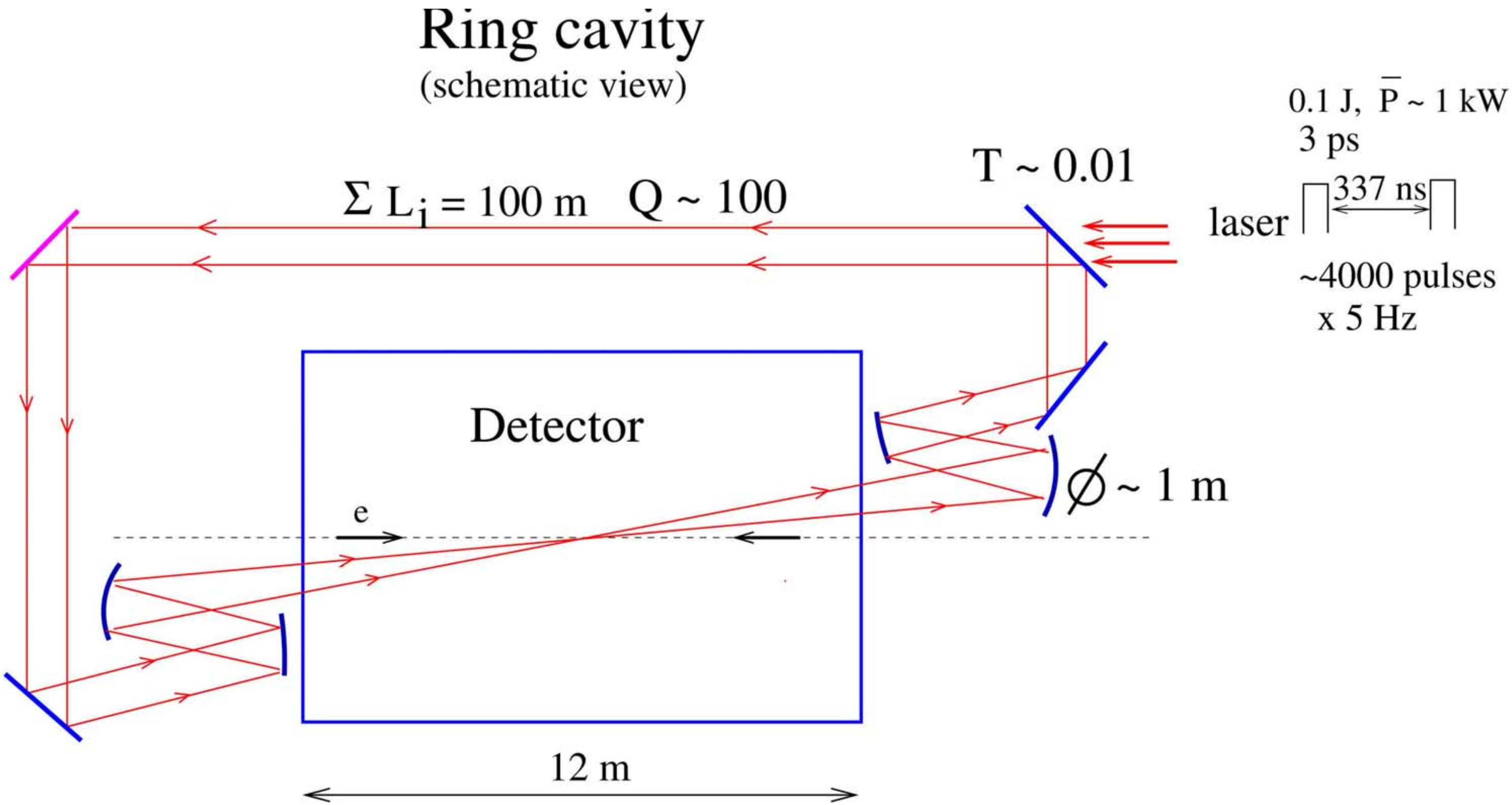
Requirements for laser

- 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

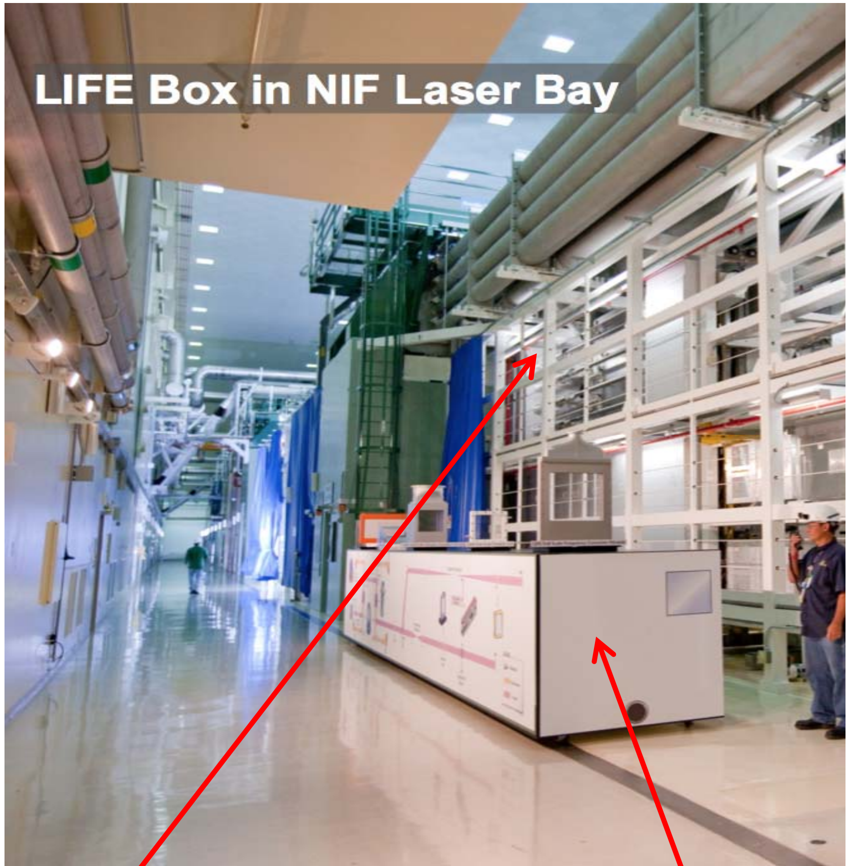


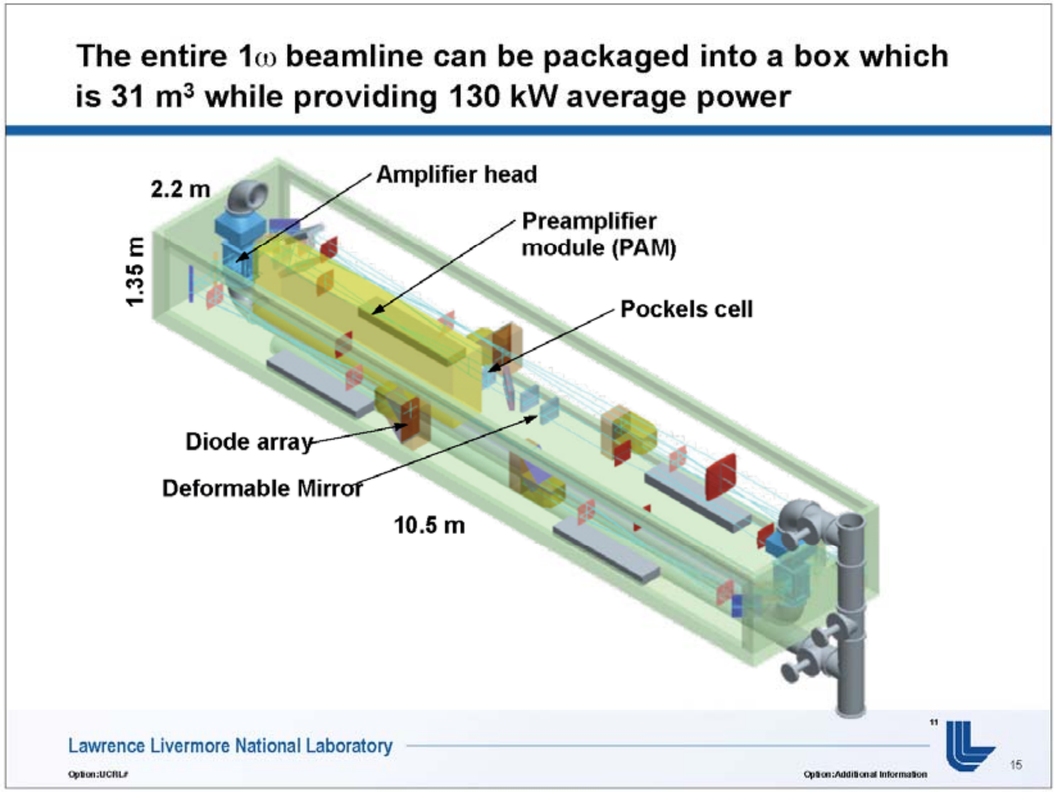
The cavity includes adaptive mirrors and diagnostics. Optimum angular divergence of the laser beam is ±30 mrad, A≈9 J (k=1), $\sigma_t \approx 1.3$ ps, $\sigma_{x,L}$~7 μm

Recently, new option has appeared, one pass diode pumped laser system, based on a 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)



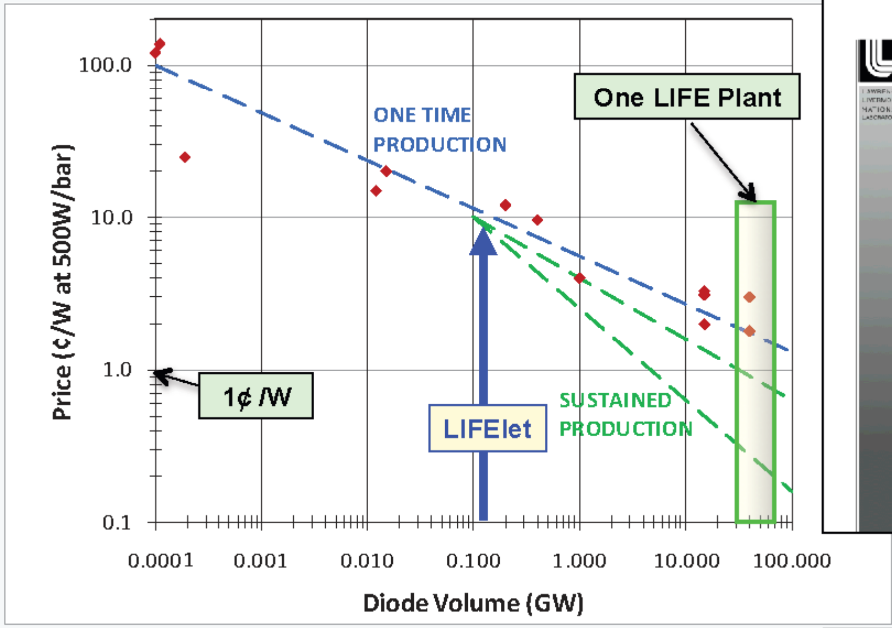


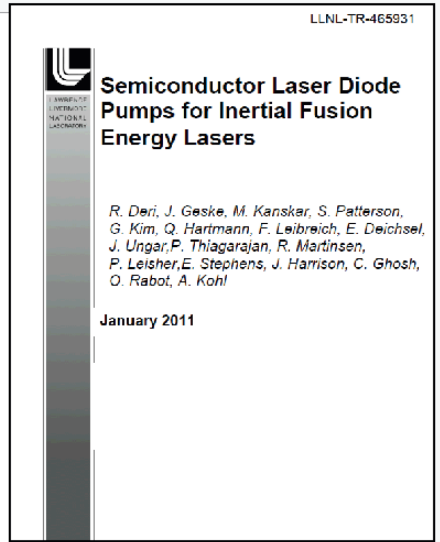
old (NIF) new(LIFE), $V=31\ m^3$

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

Laser for PLC cost ~ 3 M$

Photon collider at CLIC

Laser system for CLIC

Requirements to a laser system for PLC at CLIC (500)

Laser wavelength	~ 1 μm (5 for 2E=3000 GeV)
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

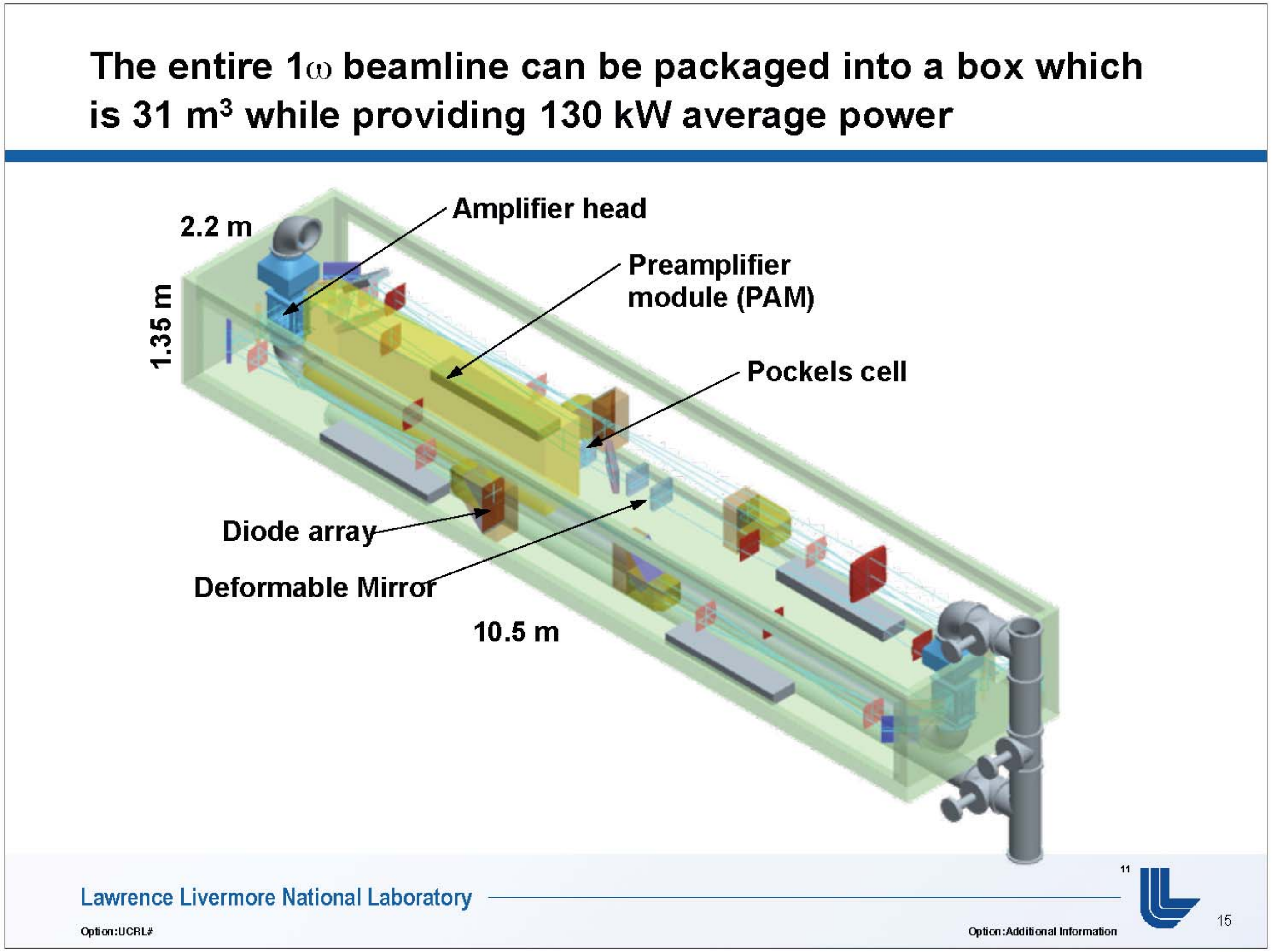
The train is too short for the optical cavity, so one pass laser should be used.

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

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)



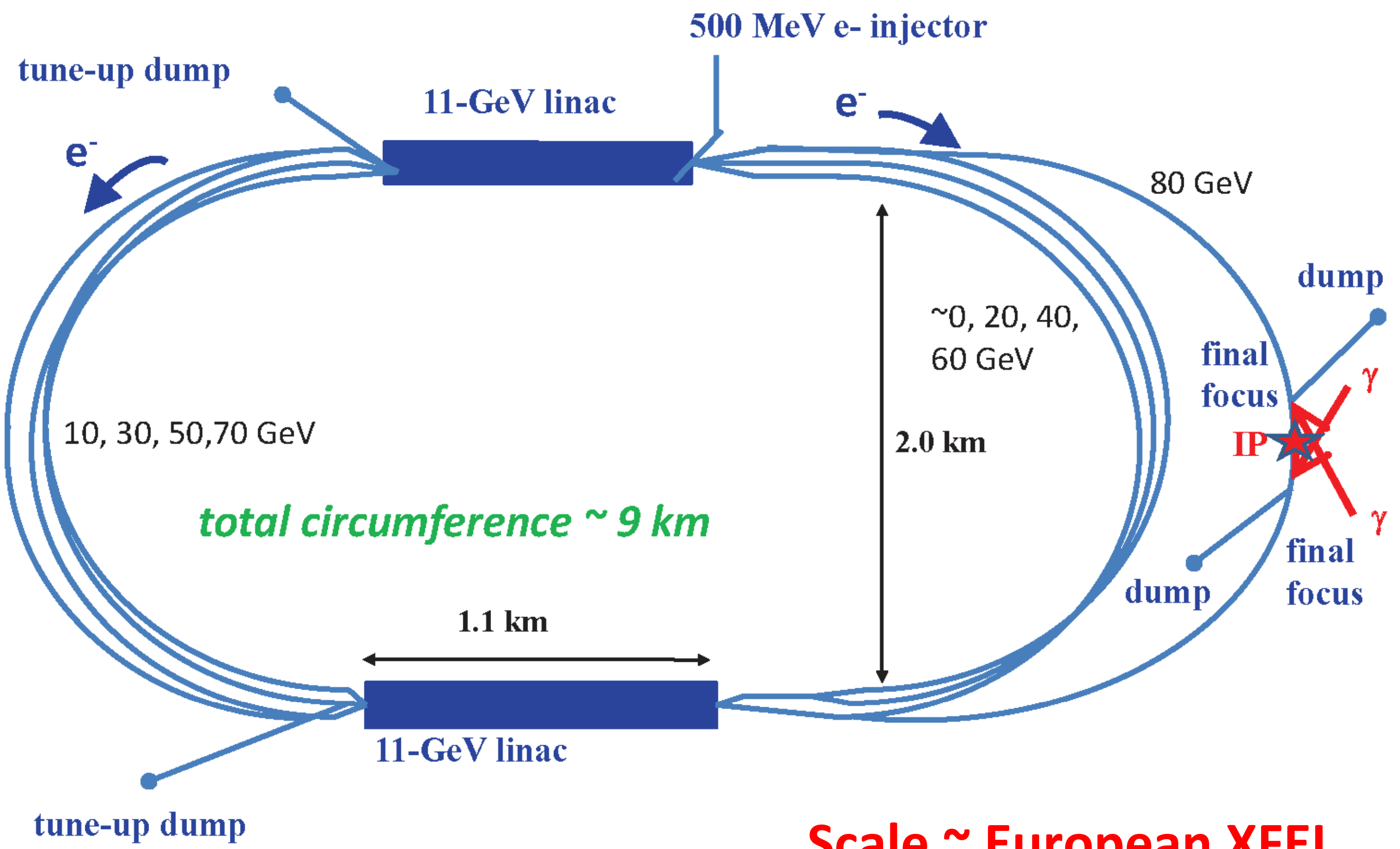
Photon collider Higgs factory SAPPHiRE

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 bunches and somewhat higher energy, 80 GeV (extra arc)

Some 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.
3. The length of the ring 9 km (2.2 km linac, 70 km ! arcs). The "usual" warm LC with G=50 MeV/m would have L~4 km total length and can work with smaller emittances and thus can have a higher luminosity. Where is a profit?

4. The PLC with E=80 GeV and λ=1.06/3 μm (x=4.6) have very low energy final electrons, this courses very large disruption angles.

Namely due to this reason for TESLA (ILC) we always considered the Higgs factory with E=110 GeV and λ=1.06 μm (x=2). In addition, at E=110 GeV the product of linear polarizations is 3 times larger (9 times smaller running time for obtaining the same accuracy for CP parameter). The energies E>100 GeV are not possible at ring colliders like Sapphire due to unacceptable emittance dilution and the energy spread (the emittance increases is proportional to E^6/R^4)

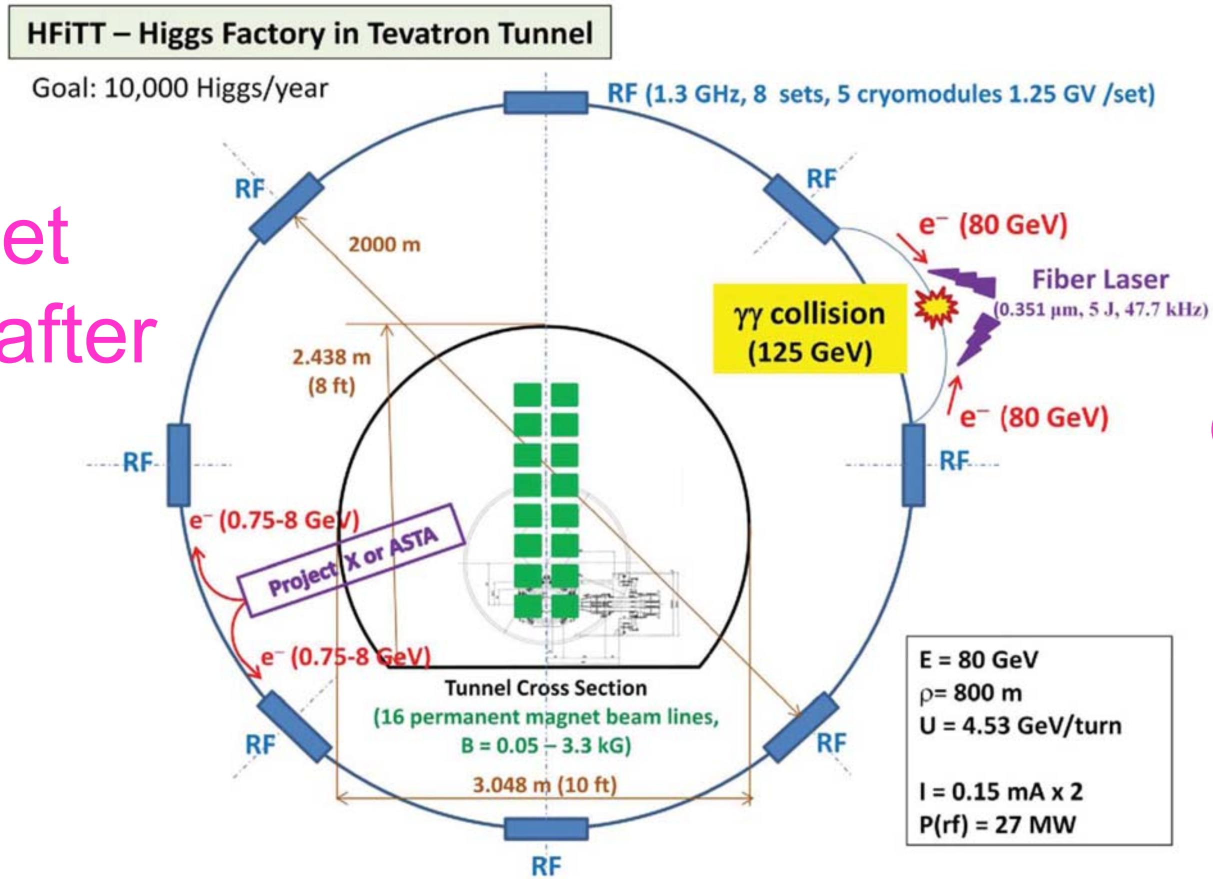
5. It is obvious that e+e- is better for the Higgs study, there is no chance to get support of physics community, if this collider is instead of e+e-(worse that precursor).

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

HFiTT – Higgs Factory in Tevatron Tunnel

W. Chou, G. Mourou, N. Solyak, T. Tajima, M. Velasco

Electrons get full energy after 8 turns



C=6 km

The total number of beamlines in the tunnel will be 16, with the total length of approximately 96 km. The eight arcs would be stacked one on top another, so electrons will jump up and down, by up to 1.5 m, 16 times per turn, 128 times in total. The vertical emittance will be completely destroyed on such "mountains"!

Laser for HFiTT

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]

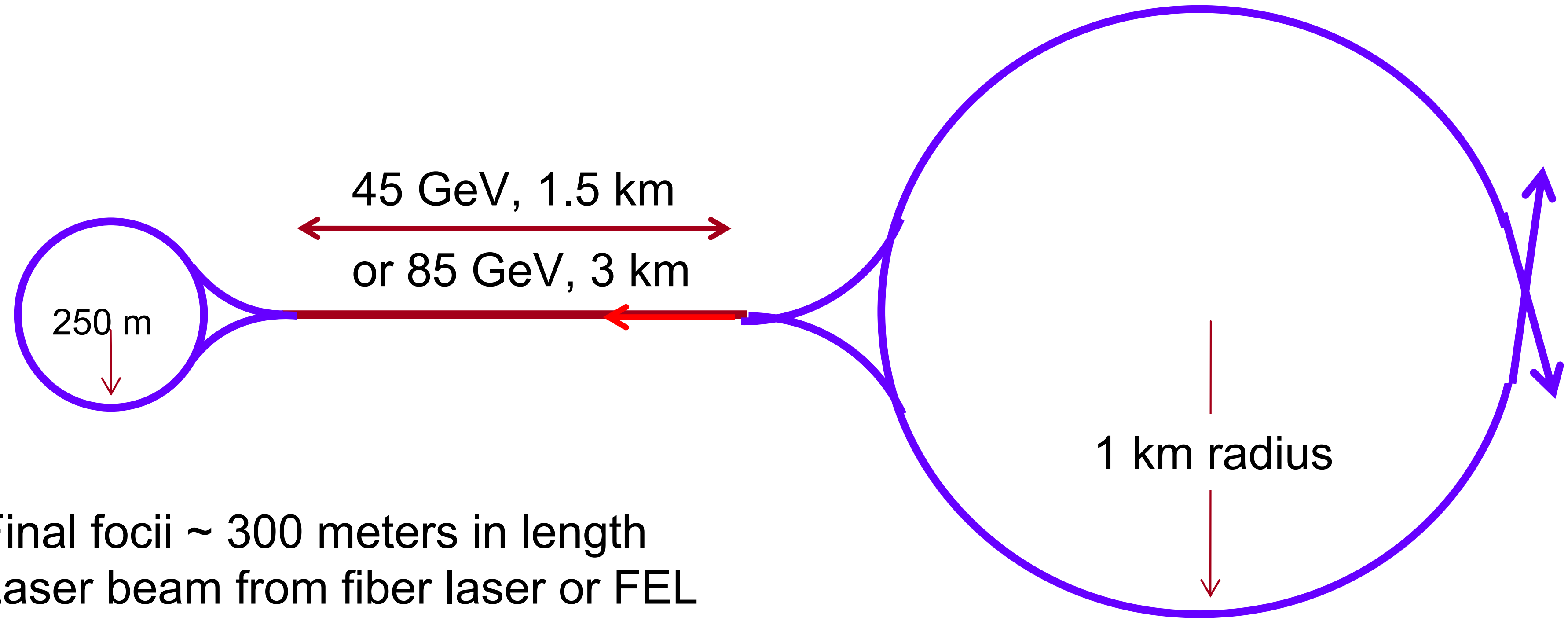
HFiTT needs 5 J at ~40kHz!

SLC-ILC-Style (SILC) Higgs Factor

(T. Raubenheimer)

- 2-pass design!

1.6 B$ without laser



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 for e+e-. Then final ring should have R=3.5 km (to preserve emittance).

My dreams of $\gamma\gamma$ factories

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

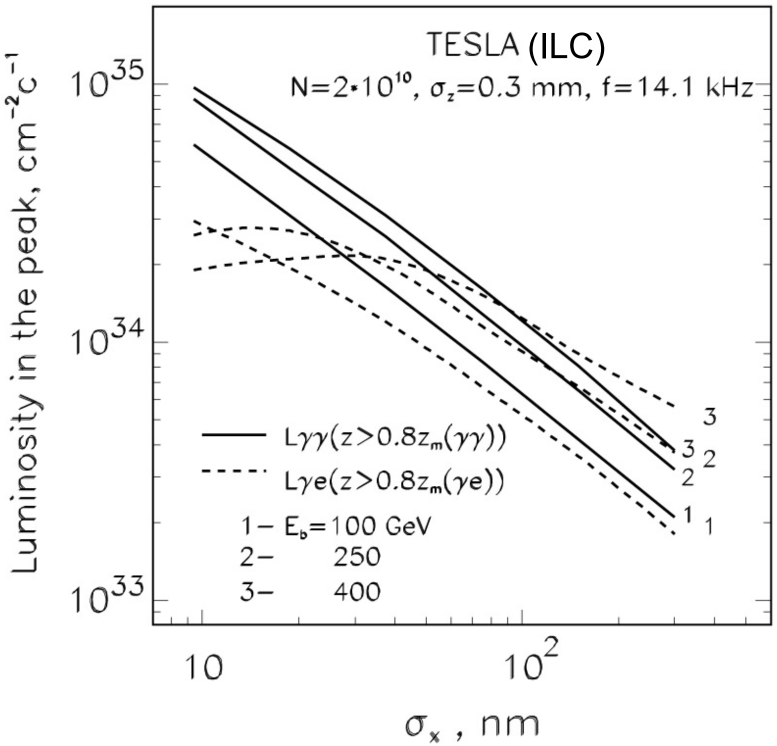
Factors limiting $\gamma\gamma,\gamma e$ luminosities

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 , $\beta_y \sim \sigma_z$

Production of beams with low transverse emittances:

(Method is based on beam combining in the longitudinal phase space)

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!

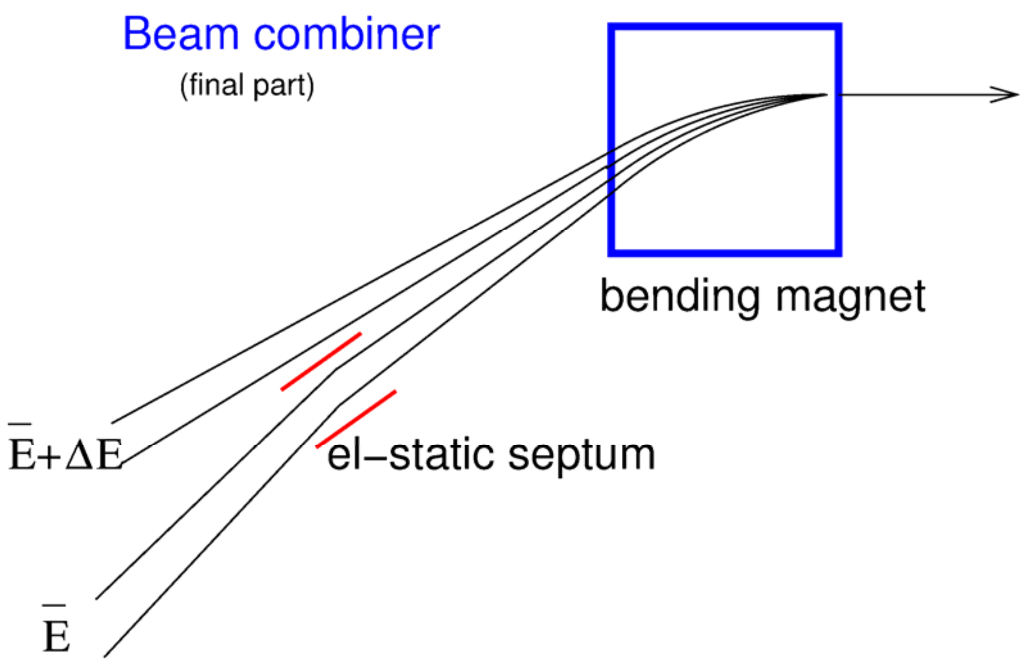
So, photoguns have much smaller longitudinal emittances than it is needed for linear collider (both e+e- or $\gamma\gamma$).

How can we use this fact?

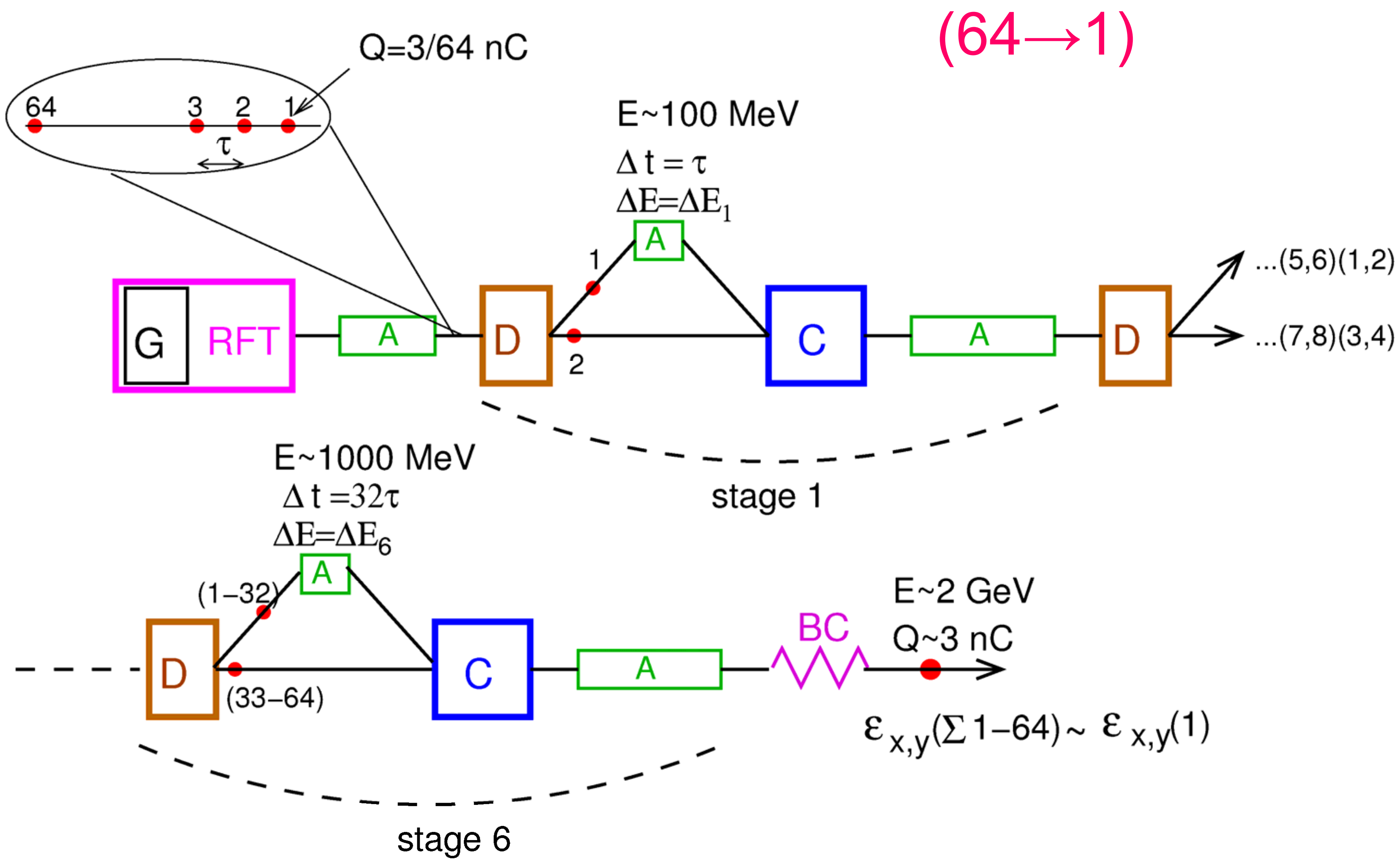
A proposed method

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)



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, it is important to change of the crossing angle from 14 to ~23-25 mrad to make ILC compatible with PLC. Due to the LIFE project one pass laser scheme becomes very attractive (easier than the optical cavity).
- PLC at CLIC is more difficult due to much shorter trains. However LIFE help here as well.
- Ring photon colliders, like SAPPHIRE and HFiTT does not look realistic due to technical problems, restriction on energy and absence of e+e- collisions. Photon colliders for Higgs study without e+e- have not sufficient physics case.
- PLC without damping rings seems 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 remarks:

$\gamma\gamma$ physics: past, present

$\gamma^*\gamma^*\to X$ at *e*+*e*+ (pp) storage rings: $dn_\gamma \sim 0.03\, d\omega/\omega$

$L_{\gamma\gamma} << L_{e+e-}$, $W_{\gamma\gamma} << 2E_0$

Future

$\gamma\gamma$, γe at linear colliders, $n_\gamma \sim n_e$, $L_{\gamma\gamma} \sim L_{ee}$, $W_{\gamma\gamma} \sim 2E_0$

1973-76 beginning of works on linear colliders at Novosibirsk
1981 idea of the photon collider
1986 Conceptual Design of VLEPP
1996-97 Conceptual Designs of NLC, TESLA/SBLC, JLC
2001 Technical Design of TESLA (this was a peak of interest to linear colliders and $\gamma\gamma$ colliders as well)
2001 Snowmass: LC is the next HEP project
2004 Technology was chosen, the first ILC workshop
2006 ILC reference design
2012 ILC technical design
2017? Decision on ILC
2019-29? Construction of ILC
2030-55 ? e^+e^- experiments at ILC (2E=250,370,500,high L)
~2055 ? beginning of $\gamma\gamma$ experiments?

Another (pessimistic) perspective: all works on linear e+e- collider can be stopped in 1-2 years due to changes in HEP strategies.

Even in this case gamma-gamma collider has a good (even better) chance because people work on acceleration method, powerful lasers and will like to realize their ideas. Photon collider is easier: no positrons, no damping rings.