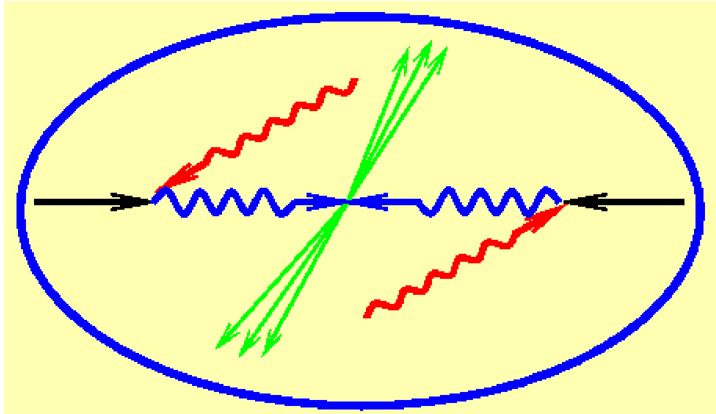


Photon colliders at future linear e^+e^- facilities and the W<12 GeV $\gamma\gamma$ collider proposal

Valery Telnov

Budker INP and Novosibirsk St. Univ.

PHOTON 2017, CERN, May 22, 2017

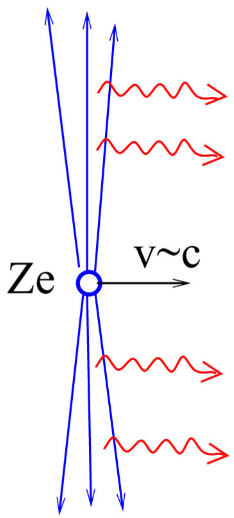
Contents

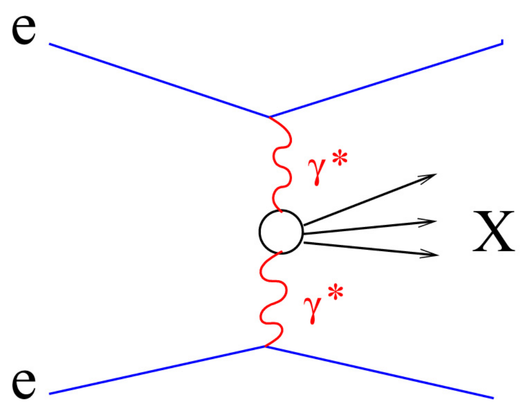
Prehistory: colliding $\gamma^*\gamma^*$ photons

(γ^* -virtual, quasi-real photon)

The idea to study some physics in photon-photon collisions is about 75 years old. The problem: a source of high energy photons.

In 30-th, Fermi-Weizsacker-Williams noticed that the field of a charged particle can be treated as the flux of almost real photons.





Landau-Lifshitz processes

Such two-photon processes have been discovered and studied at all e^+e^- storage rings since 1970th

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

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

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

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

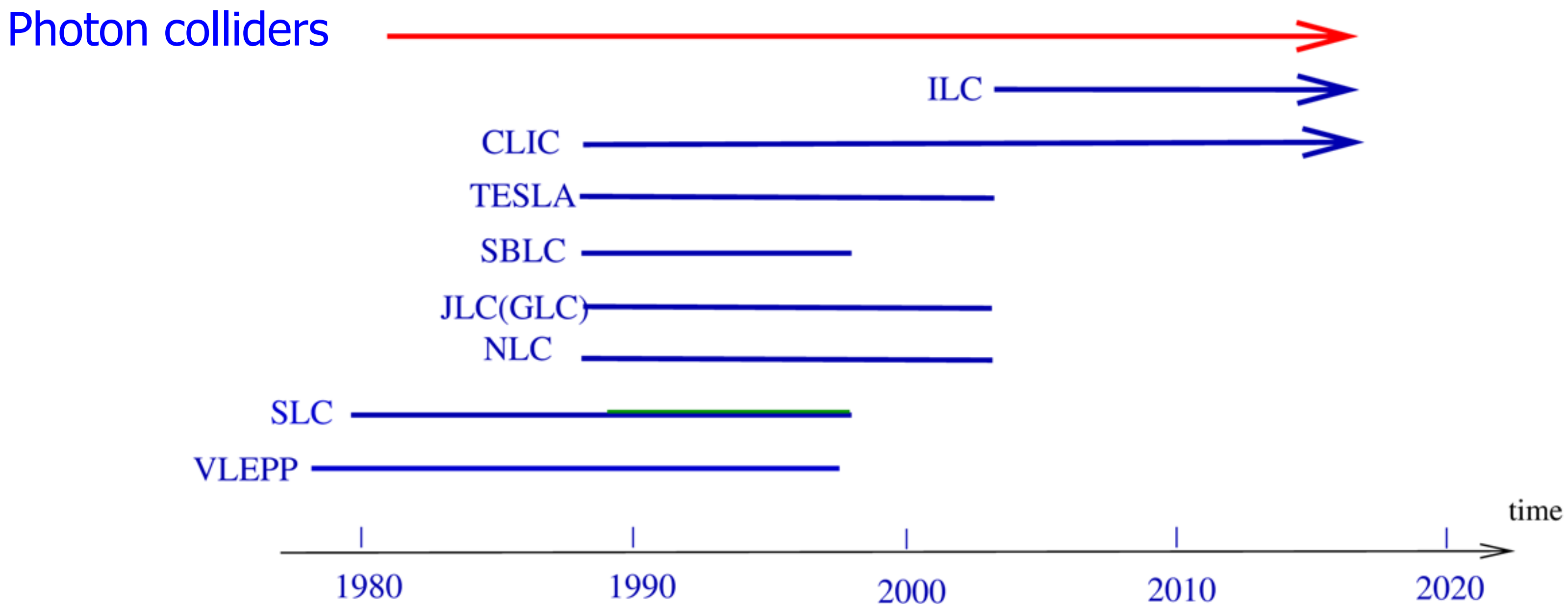
$z = W_{\gamma\gamma}/2E_0$

Idea of the photon collider (1981) based on one pass linear colliders

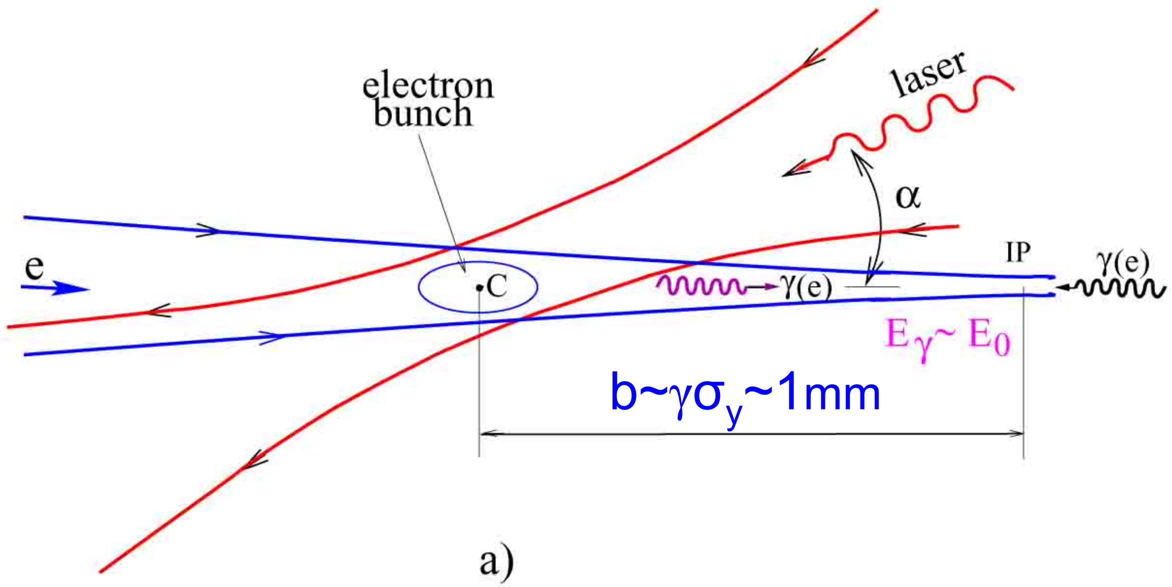
The idea of the high energy photon collider was proposed at the first workshop on physics at linear collider VLEPP (Novosibirsk,Dec.1980) and is based on the fact that at linear e^+e^- (e^-e^-) colliders electron beams are used only once which makes possible to convert electron beam to high energy photons just before the interaction point.

The best way of $e\to\gamma$ conversion is the Compton scattering of the laser light off the high energy electrons (laser target). Thus one can get the energy and luminosity in $\gamma\gamma$, γe collisions close to those in e+e- collisions: $E_\gamma \sim E_e$; $L_{\gamma\gamma} \sim L_{e\text{-}e\text{-}}$

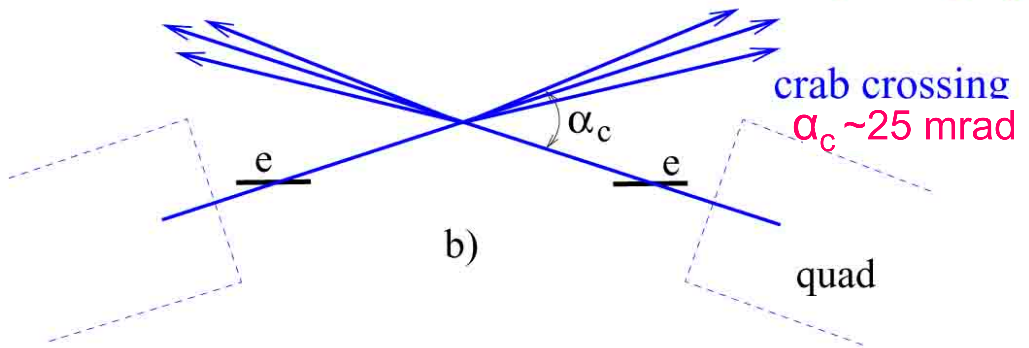
Linear colliders (projects)



Scheme of $\gamma\gamma$, γe collider



a)



b)

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

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

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

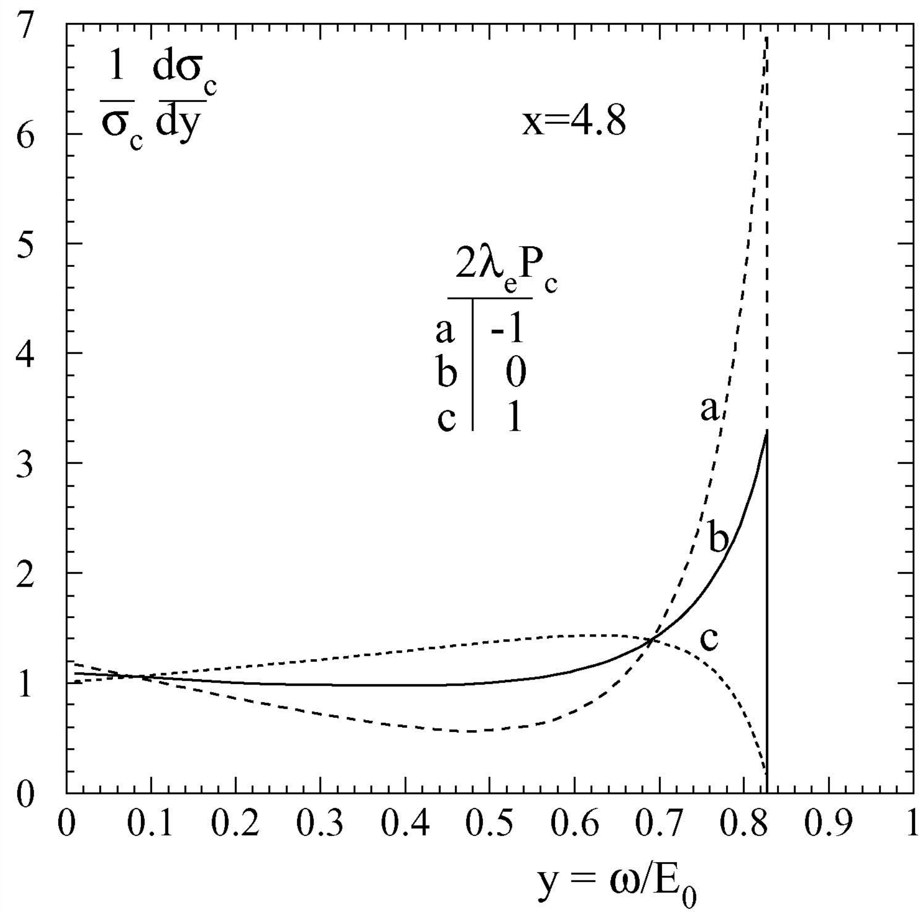
$x = 4.8$ is the threshold for
$\gamma\gamma_L \to e^+e^-$ at conv. reg.

ω_{max}~0.8 E_0

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

Electron to Photon Conversion

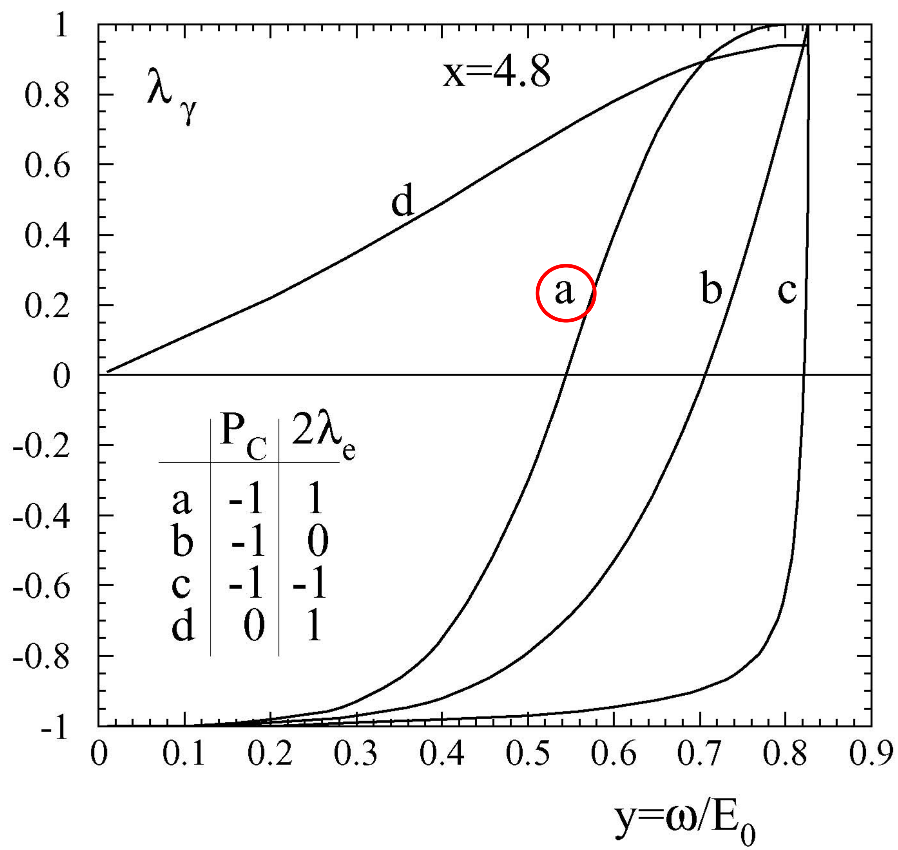
Spectrum of the Compton scattered photons



λ_e – electron longitudinal polarization

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

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



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

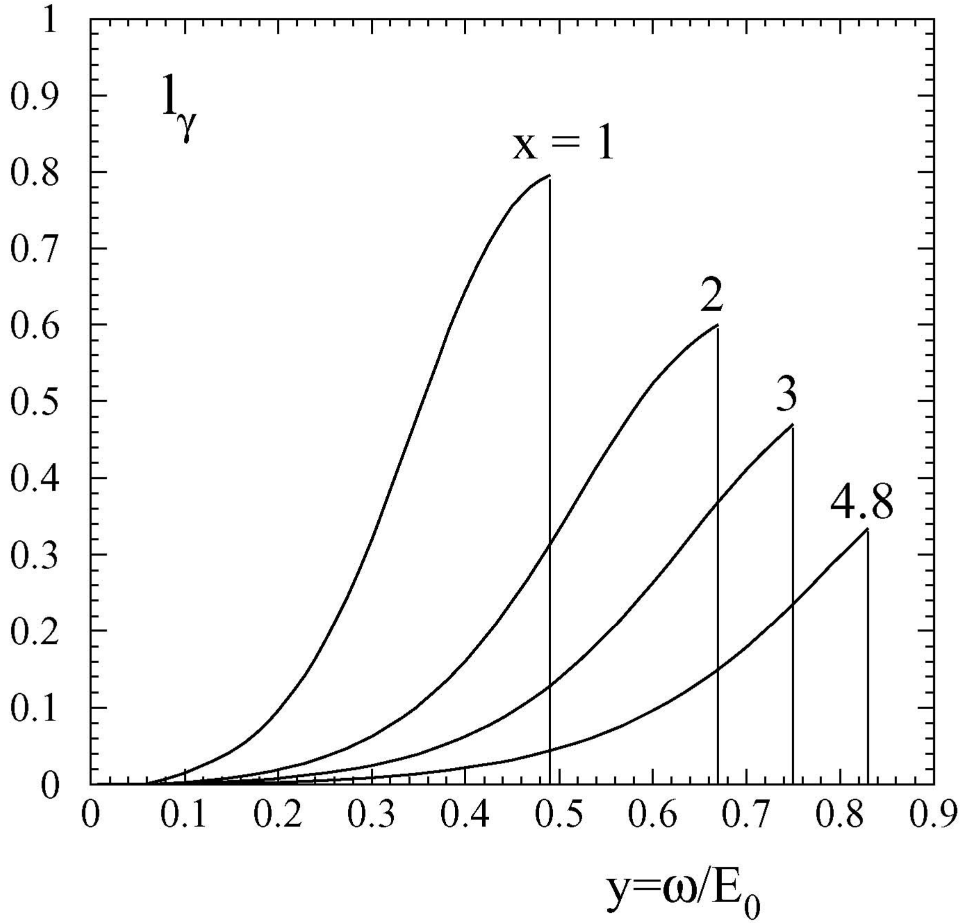
The cross section of the Higgs production

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

The cross section for main backgound

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

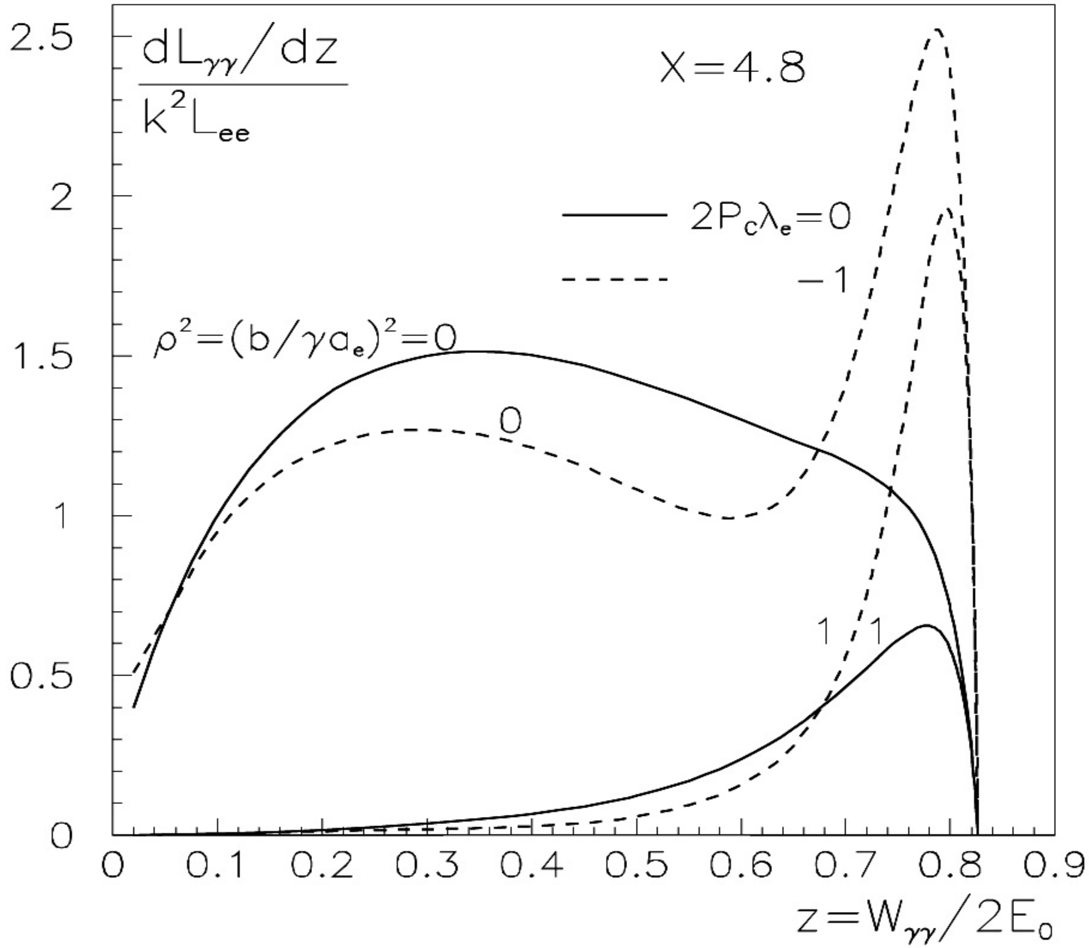
Linear polarization of photons



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

Linear polarization helps to separate H and A Higgs bosons

Ideal luminosity distributions, monohromatization



Due to angle-energy correlation high energy photons collide at smaller spot size, providing monohromatization of $\gamma\gamma$ collisions. This needs $b/\gamma > a_e$.

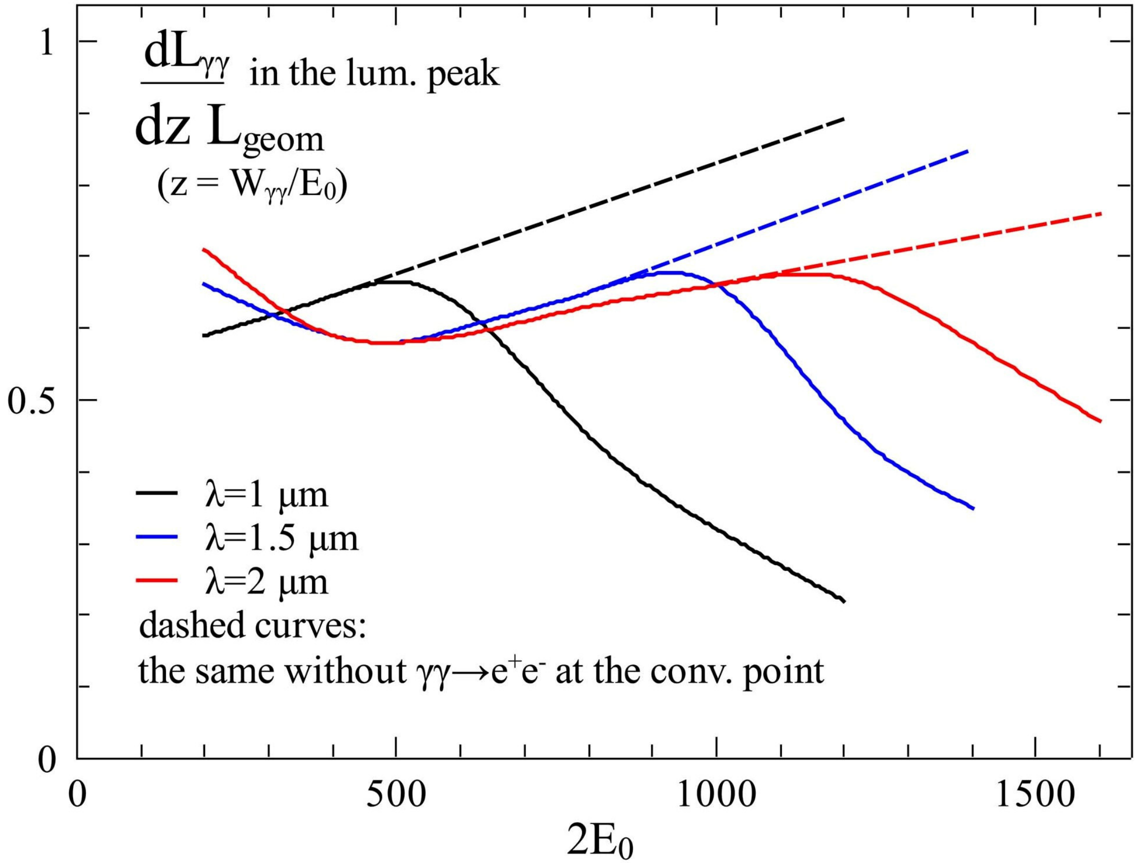
The optimum laser wavelength

The maximum energy of photons after the Compton scattering

$$\omega_{max} \approx \frac{x}{x+1} E_0, \qquad x = \frac{4E_0\omega_0}{m^2c^4}$$

For x>4.8 the luminosity in the high energy lum. peak decreases due to e+e- pair creation in collision of laser and high energy photons at the conversion point.
For the maximum collider energy E_0 the optimum laser wave length (x=4.8) is

$$\lambda\ [\mu m] \approx 4E_0[TeV]$$



λ=1 μm for $2E_0$<500-600 GeV,
λ=2 μm for $2E_0$<1.2 TeV

Laser flash energy

For e→γ conversion one needs thickness (t) of laser target equal about one Compton collision length ($p=t/\lambda_C \sim 1$). The required flash energy is determined by σ_c , geometric properties of laser and electron beams and by nonlinear effects in Compton scattering described by parameter $\xi^2 = \frac{e^2 \overline{F}^2 \hbar^2}{m^2 c^2 \omega_0^2} = \frac{2 n_\gamma r_e^2 \lambda}{\alpha}$ which should be kept small (0.15-0.3),

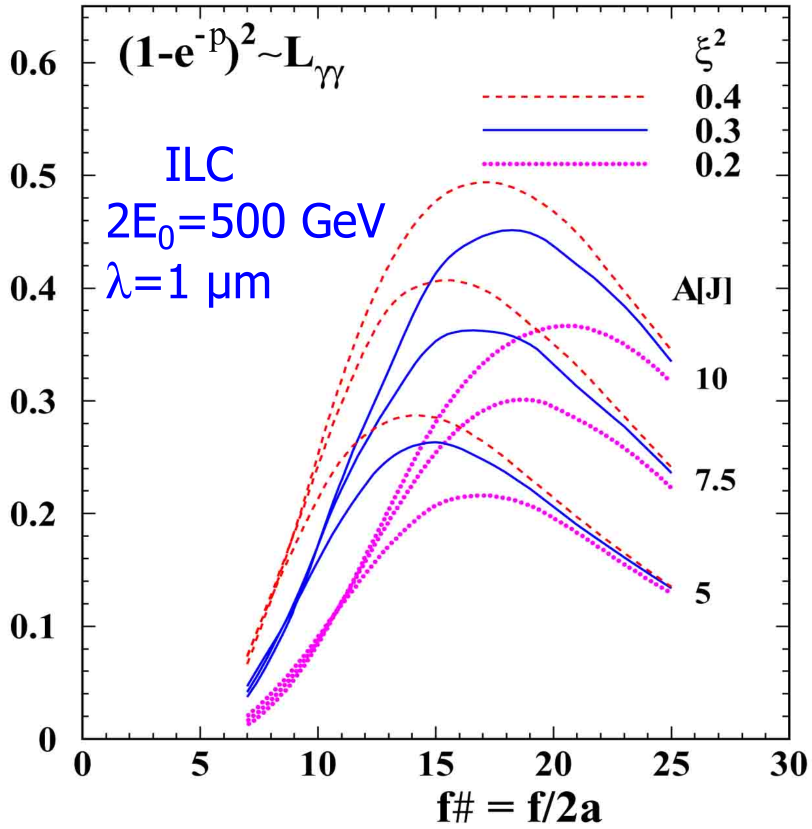
because $\omega_m = \frac{x}{x+1+\xi^2} E_0$.

It is reasonable to keep

$$\Delta\omega_m / \omega_m \approx \xi^2 / (x+1) < 0.05$$

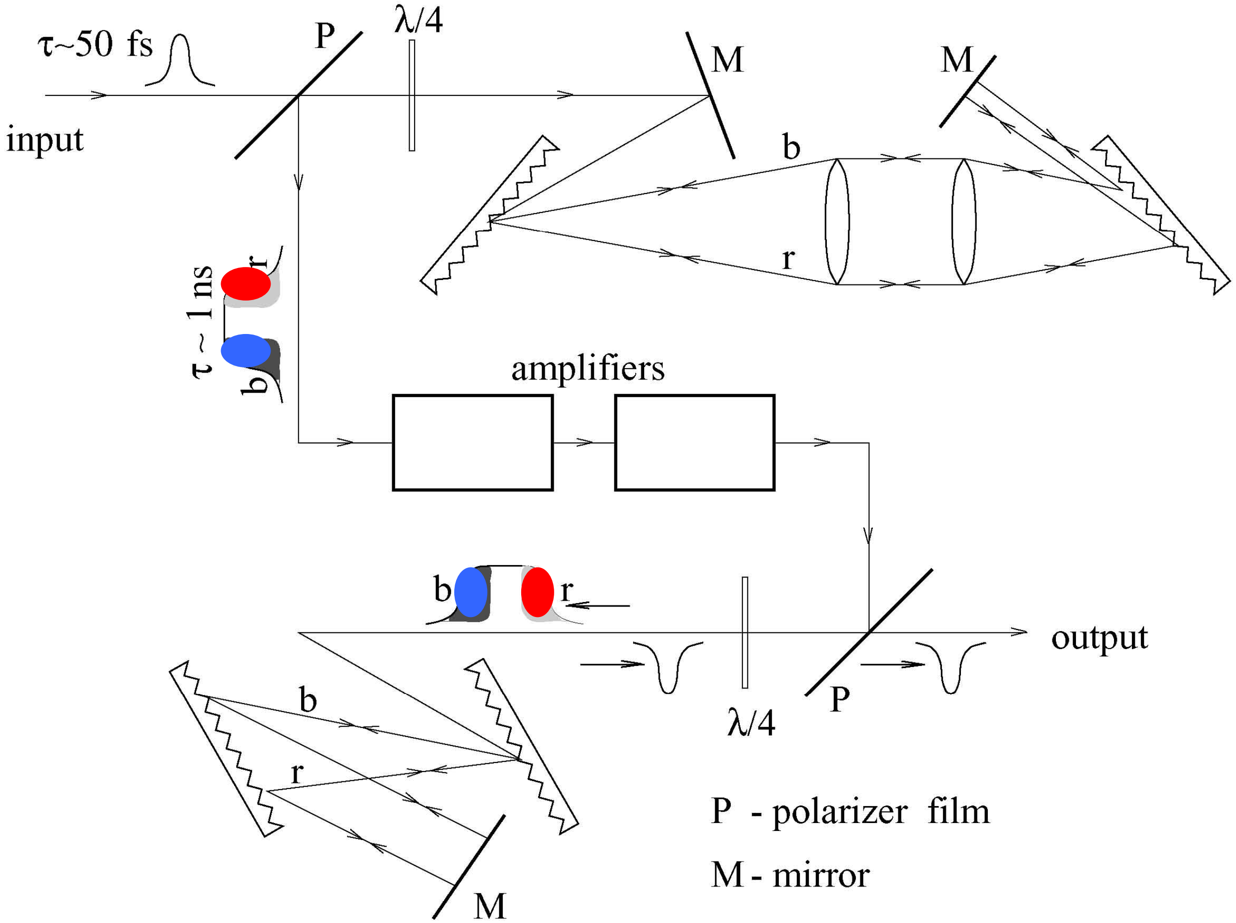
then for x=4.8 $\xi^2 < 0.3$

For $\lambda=1$ μm ($2E_0=500$ GeV) the required flash energy is about A~10 J and it increases for larger λ (or E_0) due to the nonlinear effect.
It is determined by laser diffraction and geometric beam parameters at short λ and by nonlinear effects at large λ (multiTeV collider).



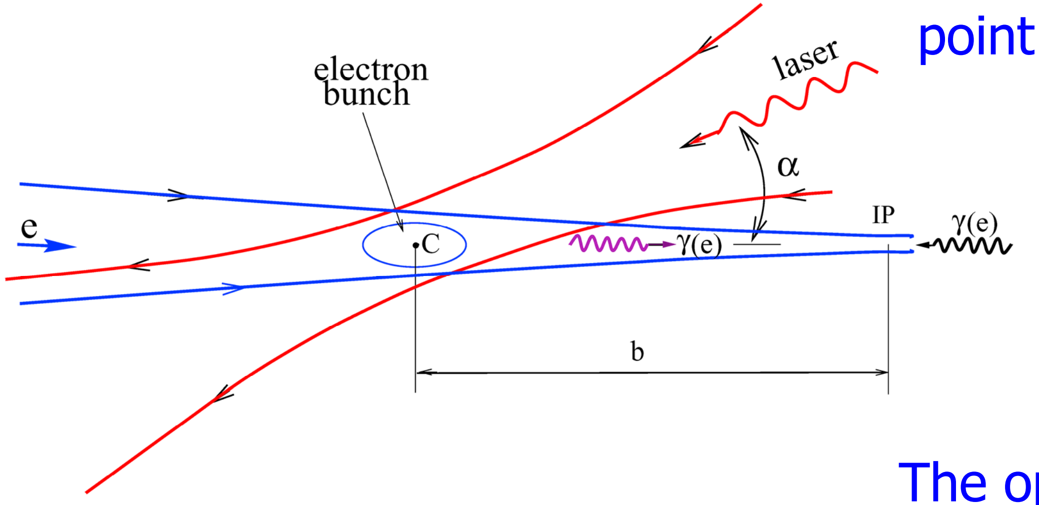
Chirped pulse laser technique (D.Strickland, G.Mourou, 1985) made photon colliders idea really feasible

Stretching-amplification-compression allows to avoid nonlinear effects (self-focusing) during amplification and thus to increase laser a power by a factor of 1000! Tens Joule pulses of ps duration became a reality.

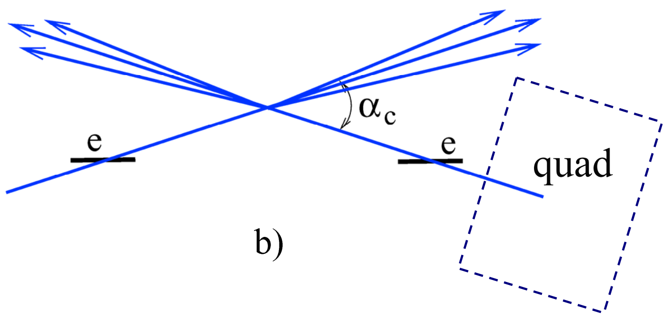


Other technologies important for the photon collider: diode pumping, adaptive optics, high reflective multilayer mirrors for high powers – all is available now.

Collision scheme



a)



b)

Minimum distance (b) between the interaction point (IP) and conversion point (CP)

$$b \approx 3\sigma_z + 0.1E[\text{TeV}], \quad \text{cm}$$

2-nd term is the distance equal to one Compton collision length at x=4.8 and ξ^2=0.3.

The optimum CP-IP distance corresponds to the case when an additional transverse size due to photon divergence in Compton scattering is equal to electron beam size

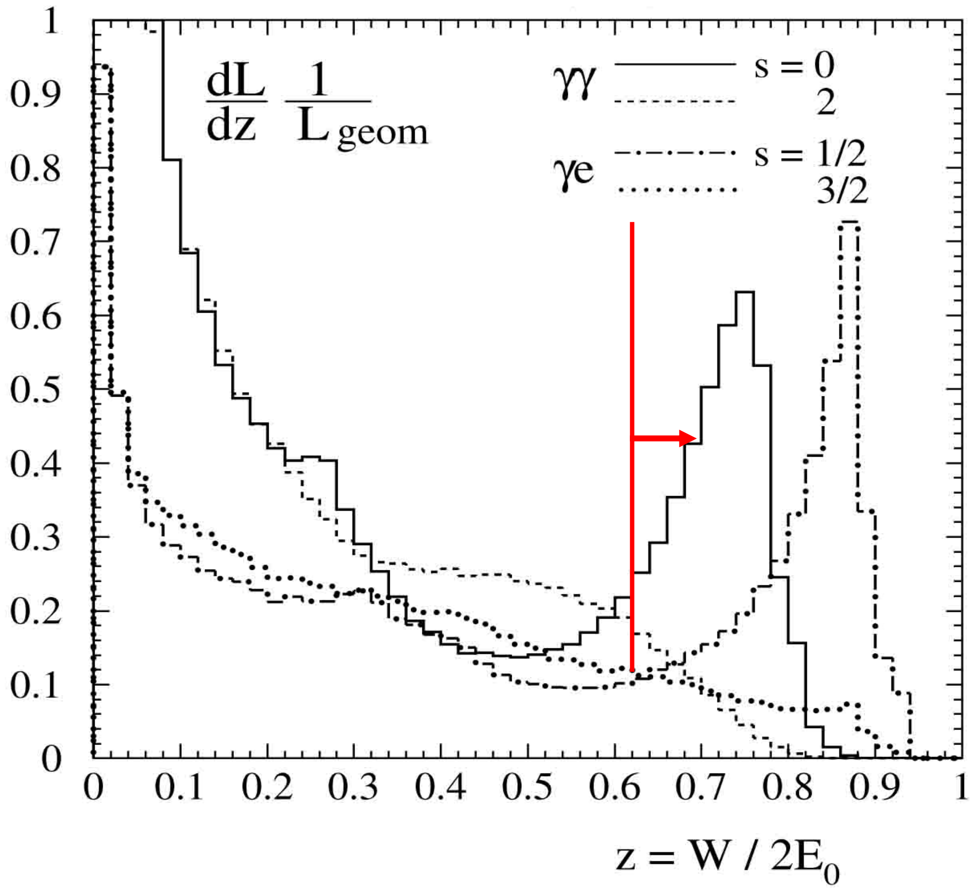
$$\sigma_y \sim b/\gamma$$

For ILC(500) σ_y ~5 nm → b ~ 2.5 mm

Typical $\gamma\gamma$, γe luminosity spectra

simulation with account all important effect at CP and IP regions:
multiple Compton scattering in CP, beamstrahlung, coherent pair creation, beam repulsion e.t.c.

ILC(500)

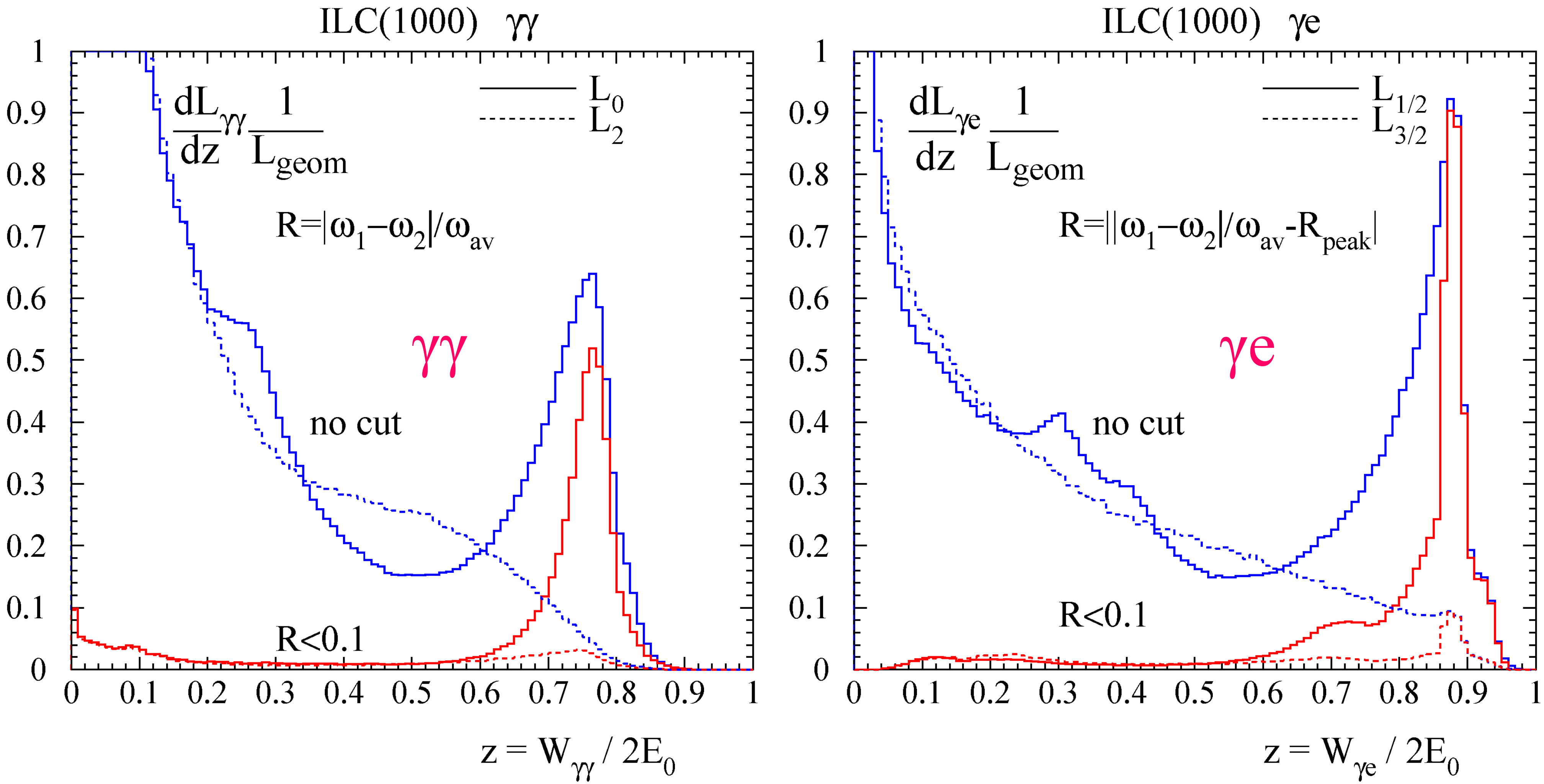


Luminosity spectra and their polarization properties can be measured using QED processes

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

Luminosity spectra at ILC(1000) with λ=2 μm

(red curves with restriction on longitudinal momentum of produced system)



Such γγ collider would be the best option for study of X(750)

(fake γγ peak observed at LHC in 2015-2016)

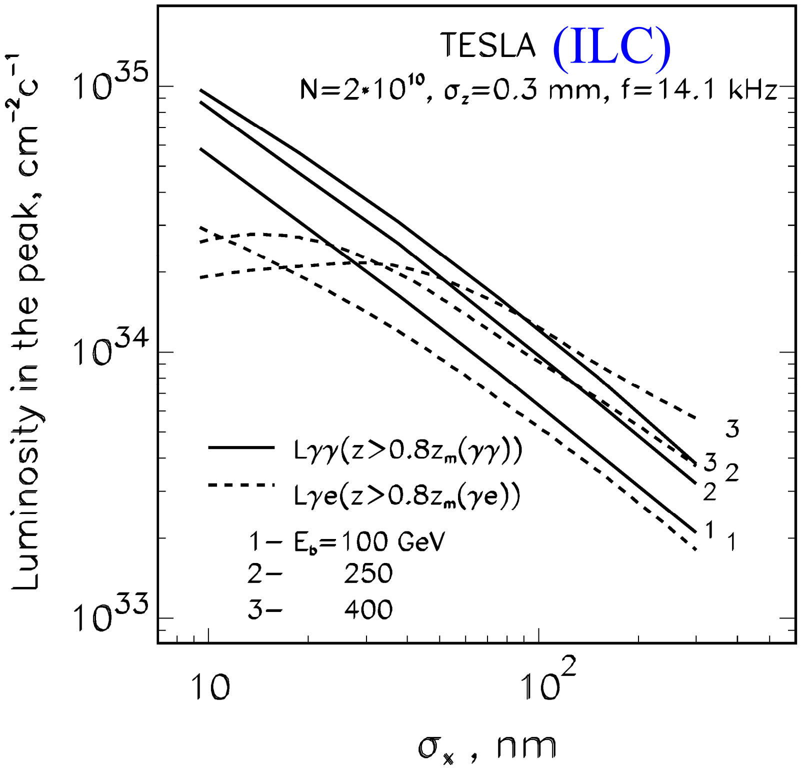
Factors limiting γγ,γe luminosities

Main collision effects at the IP:

γγ	•coherent pair creation
γγ, γe	•beamstrahlung
γe,ee	•beam-beam repulsion

Coherent pair creation:

high energy photons convert to e+e- pair on the field of the opposing electron beam, it is the only collision effect limiting γγ-luminosity, important for multi-TeV colliders and short beams.

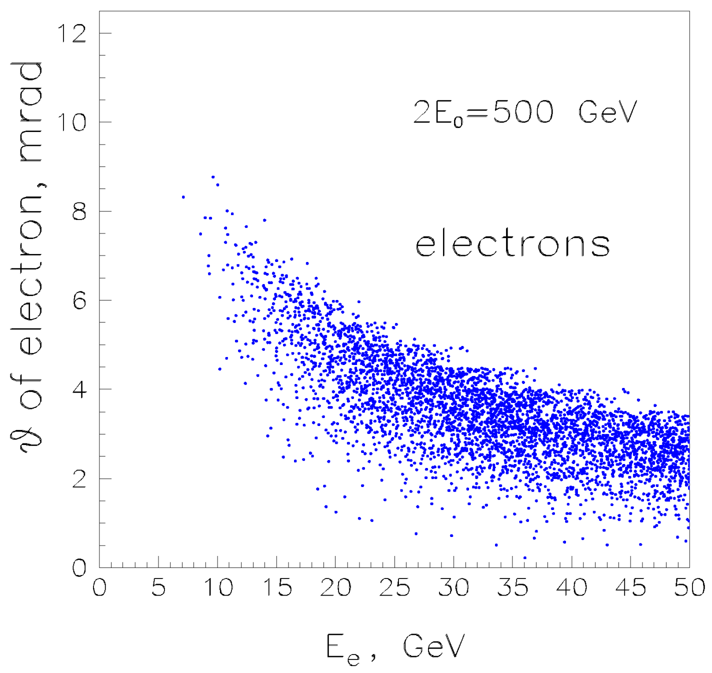


At ILC σ_x~200-300 μm (limited by emittance). This figure shows that one order higher luminosity is possible with smaller beam sizes.

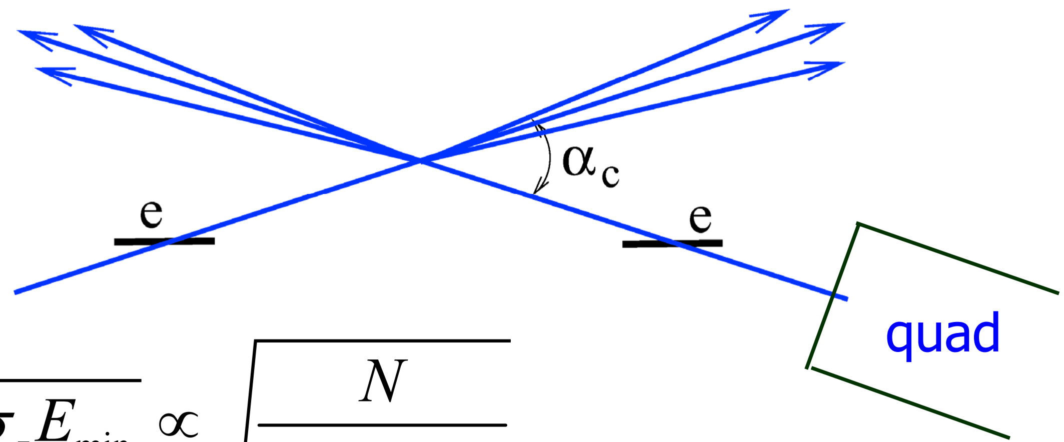
For 2E<1 TeV the γγ-luminosity is determined only by geometric e-e- luminosity, which depends on beam emittances: $L \propto 1/\sqrt{\varepsilon_{nx}\varepsilon_{nx}}$.

At present electron guns give the product of emittances several times larger than with damping rings, further improvements (combining, cooling) of electron sources (polarization is very desirable) are needed for photon colliders without damping rings.

Removal of disrupted beams, crossing angle, beamdump



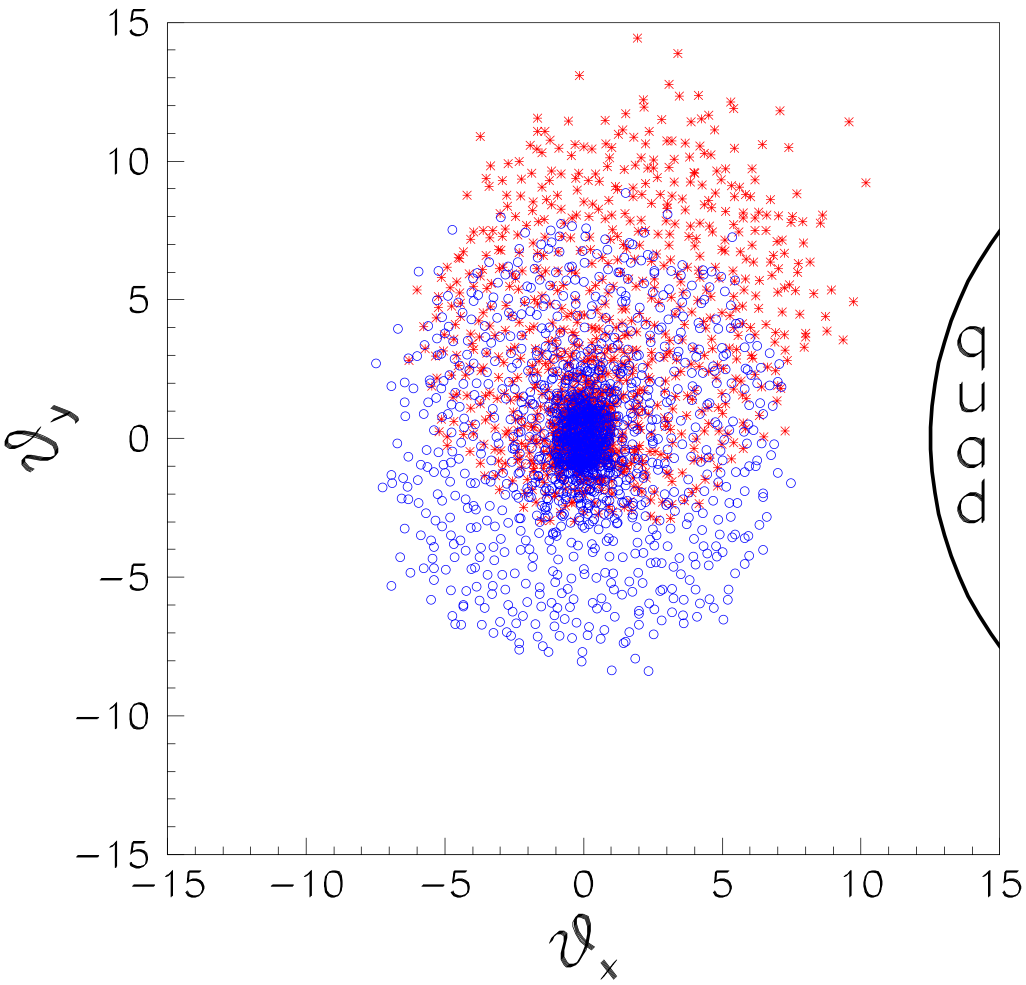
Removal of disrupted beams from the detector is one of most serious problem for the photon collider. After the interactions beams have very wide energy spread: $E \approx (0.02\text{-}1)E_0$ and large disruption angle (about 10 mrad at ILC). The problem is solved by using crab-crossing scheme where beams travels outside final quads.



$$\theta_d \propto \sqrt{N/\sigma_z E_{\min}} \propto \sqrt{\frac{N}{\sigma_z \sigma_c(x) \lambda}}$$

Angular size of quads 5/400~12 mrad, so for PLC at ILC crossing angle about 25 mrad is needed (14 mrad is now for e+e-). Using λ =2 μm (instead of 1 μm) allows to decrease α_c from 25 to 20 mrad, this solution completely compatible with e+e-.

Disrupted beam with account of the detector field (at the front of the first quad at L=4 m)

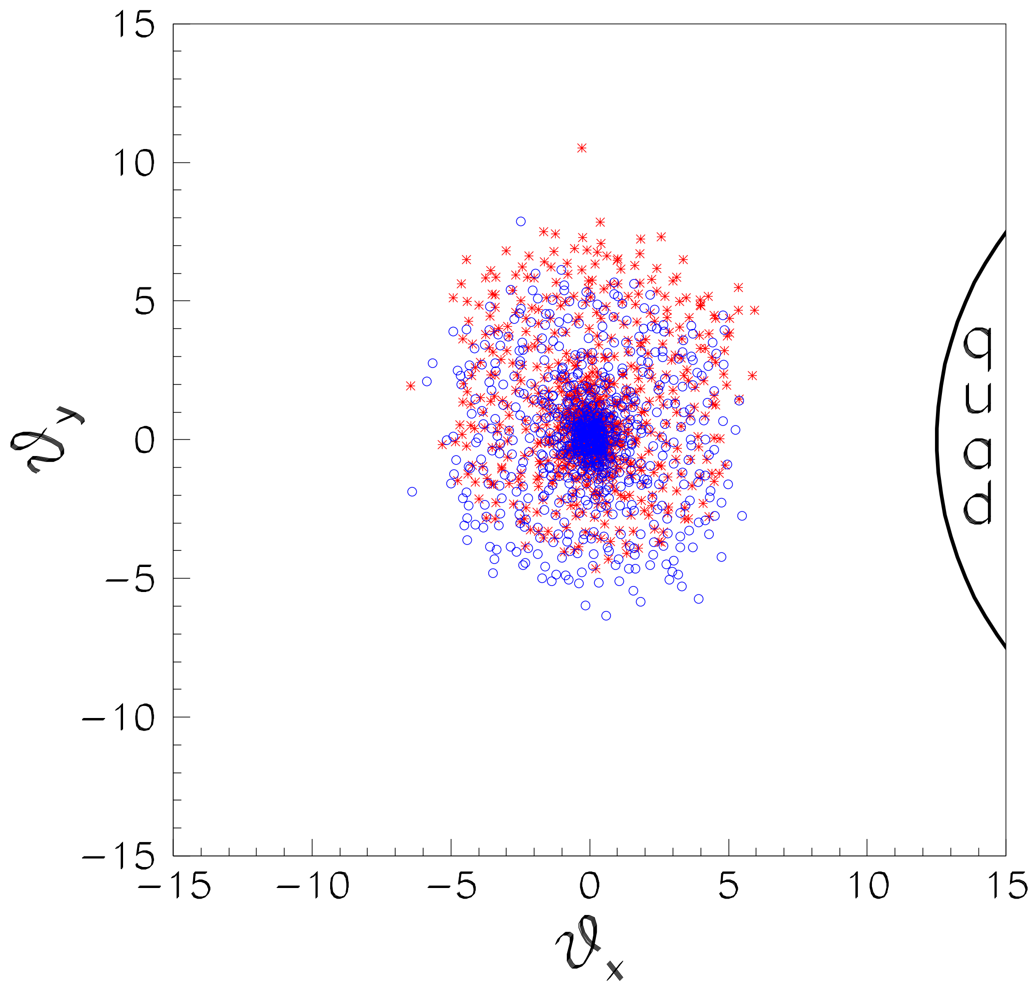


$2E_0$=500 GeV, λ=1 µm

E_{min}≈5 GeV

α_c=25 mrad

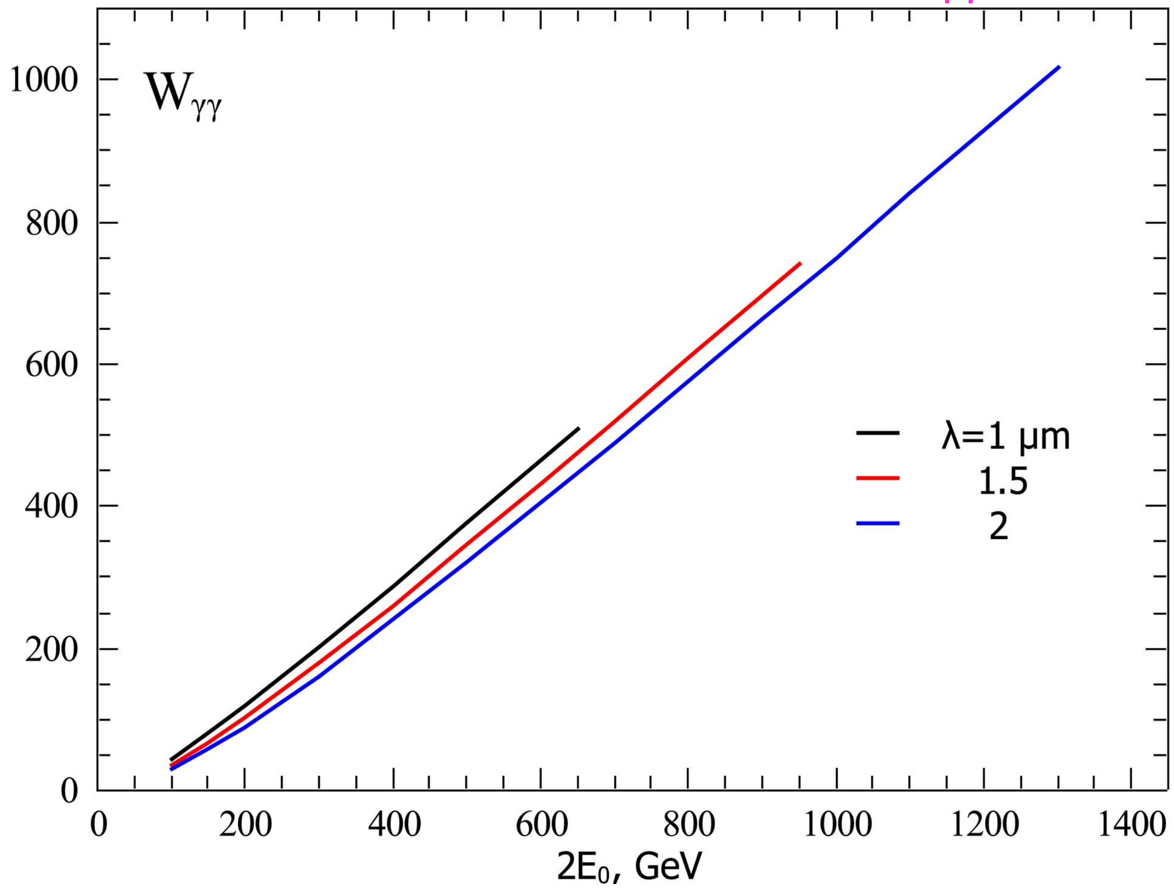
→



$2E_0$=1000 GeV, λ=2 µm

α_c=20 mrad

The dependence of $W_{\gamma\gamma}$ on the laser wavelengh



Here $W_{\gamma\gamma}$ corresponds to the peak of lum. spectra

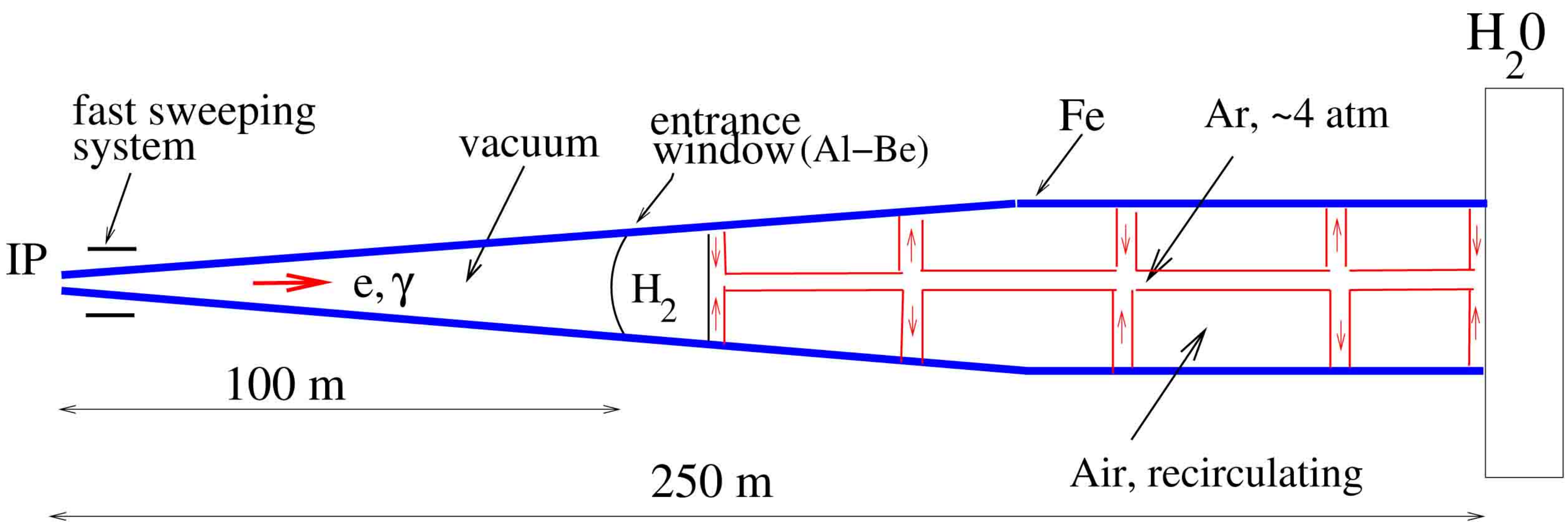
The energy $2E_0$ required for the study of the H(125) and top threshold

λ, μm	1	1.5	2	
H (125)	210	235	255	21%
top(360)	485	520	550	13.4%

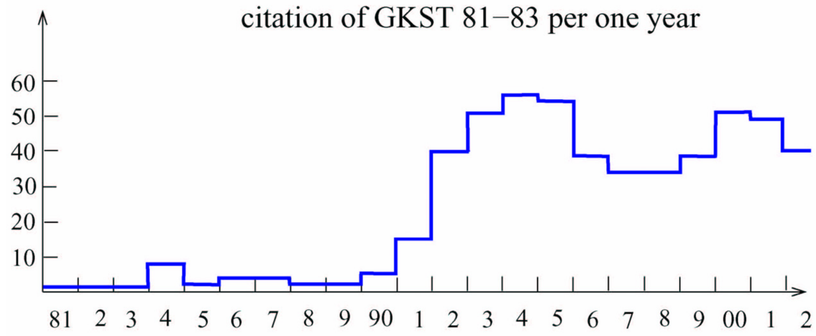
In order to have at the PLC with λ=2 μm the same energy reach as with λ=1 μm with $2E_0$=500 GeV one need $2E_0$=565 GeV (or 13% higher only).

Photon collider produces a very narrow powerful gamma beam (and a wide electron beam) therefore a special beam dump is needed

Possible solution



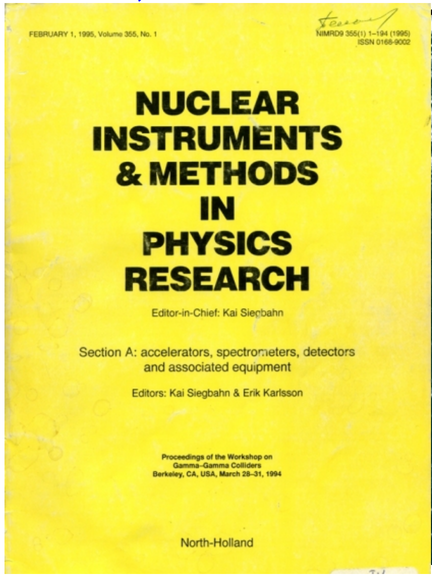
Activity on photon colliders



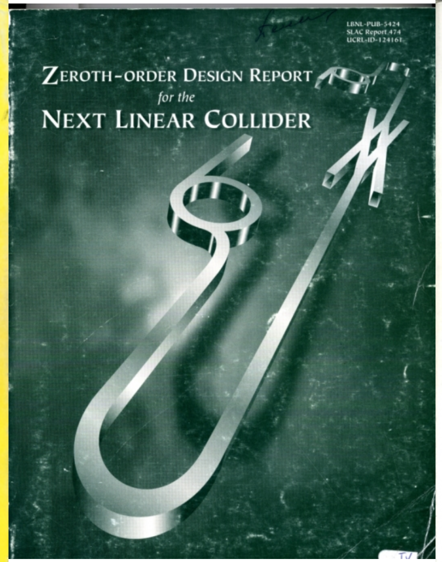
(total number of publications is larger by a factor of 2)

→ about 2 papers/week

Gamma-gamma workshop LBL, 1994

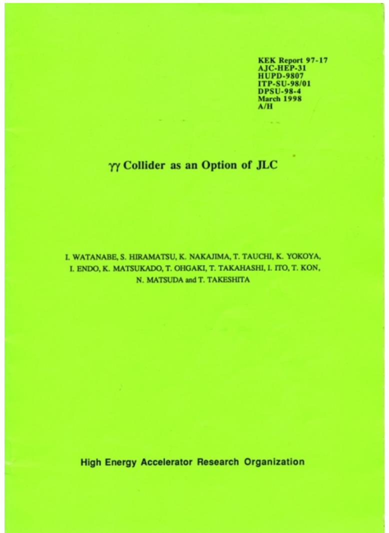


NLC

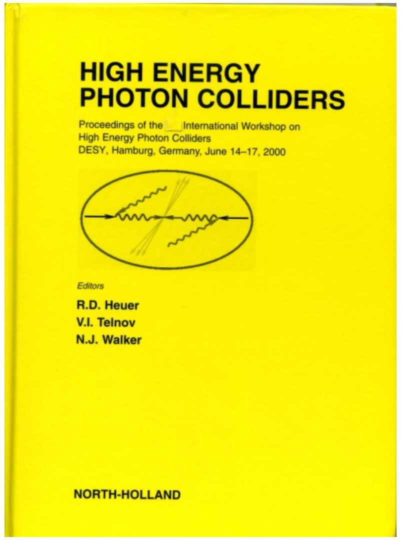


TESLA CDR

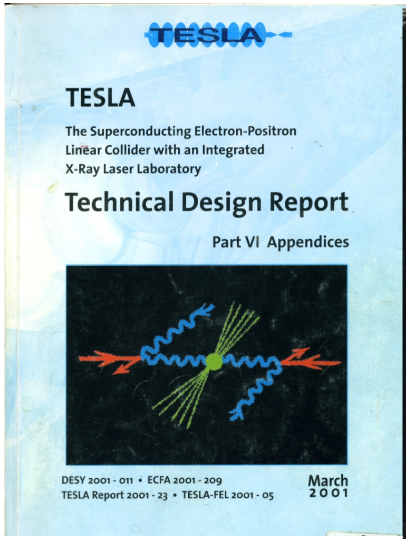
γγ at JLC



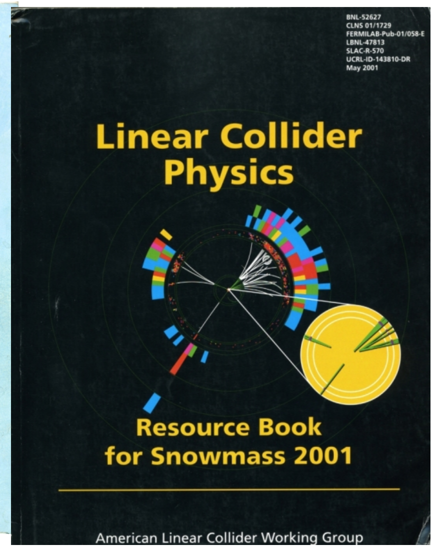
γγ workshop at DESY



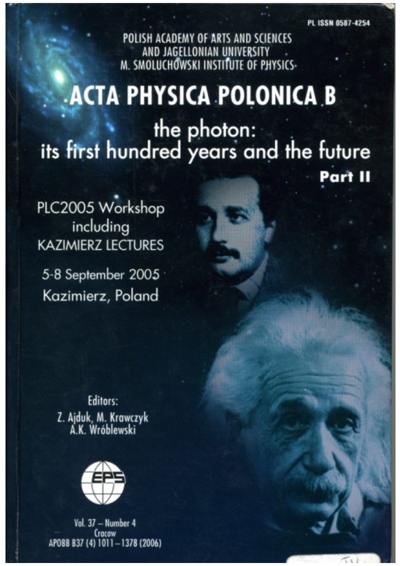
TESLA TDR



γγ NLC

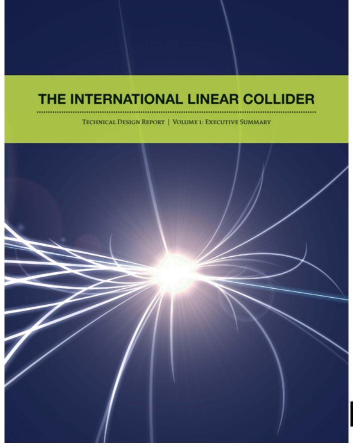


PLC 2005



Photon colliders were suggested in 1981 and since ~1990 are considered as a natural part of all linear collider projects.

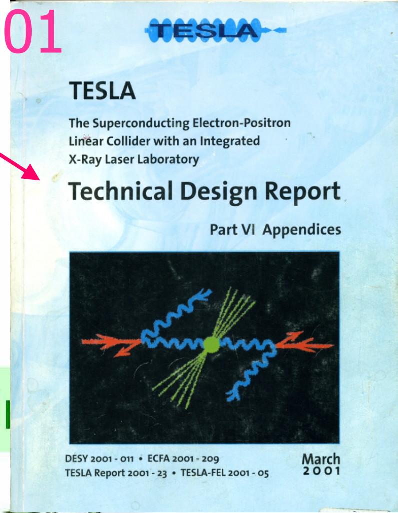
Photon colliders at ILC and CLIC

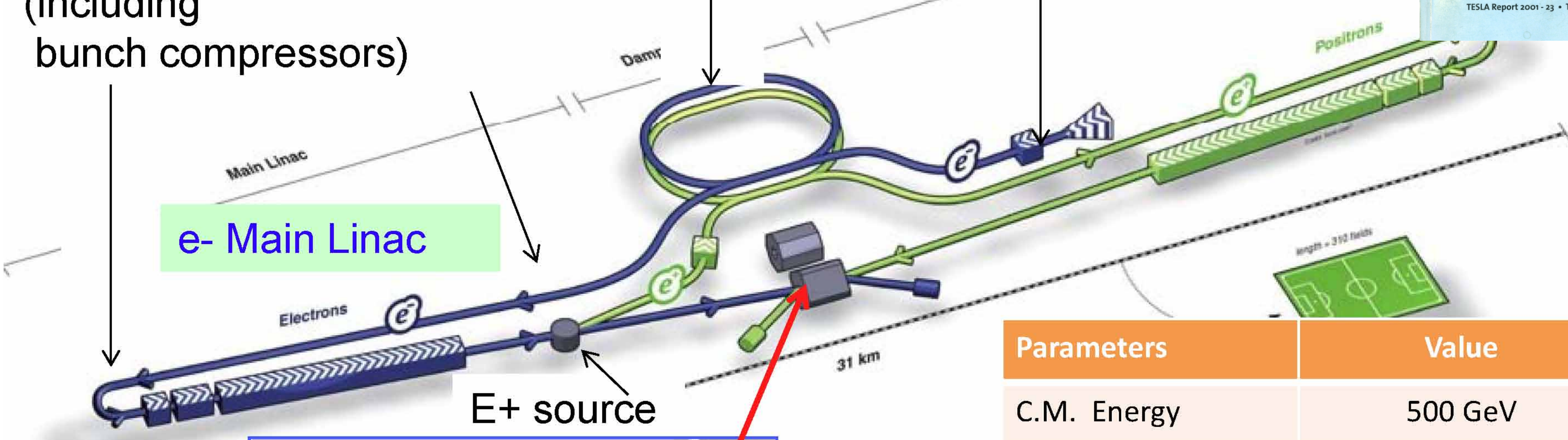


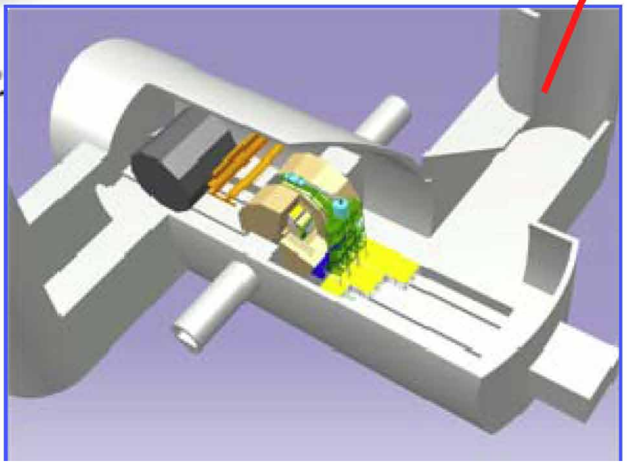
ILC TDR
6.2013

ILC TDR Layout

PLC at TESLA, 2001







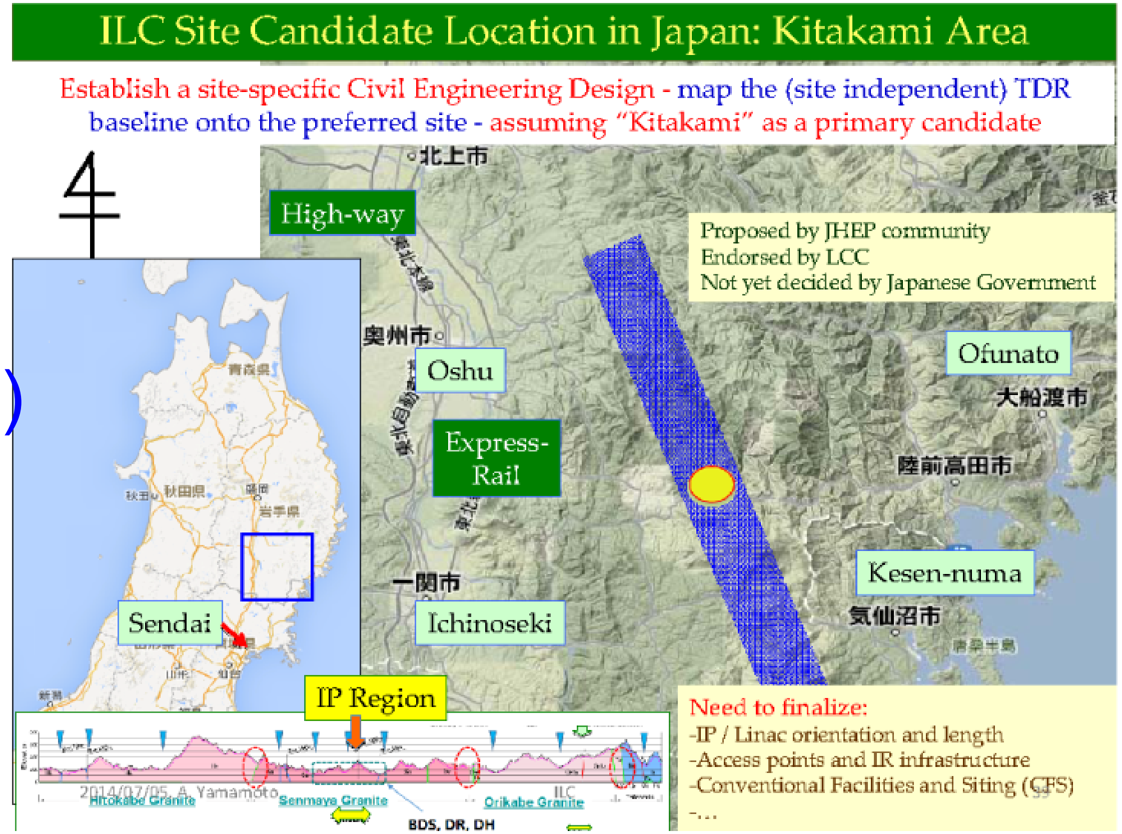
L=31 km
2E=500 GeV

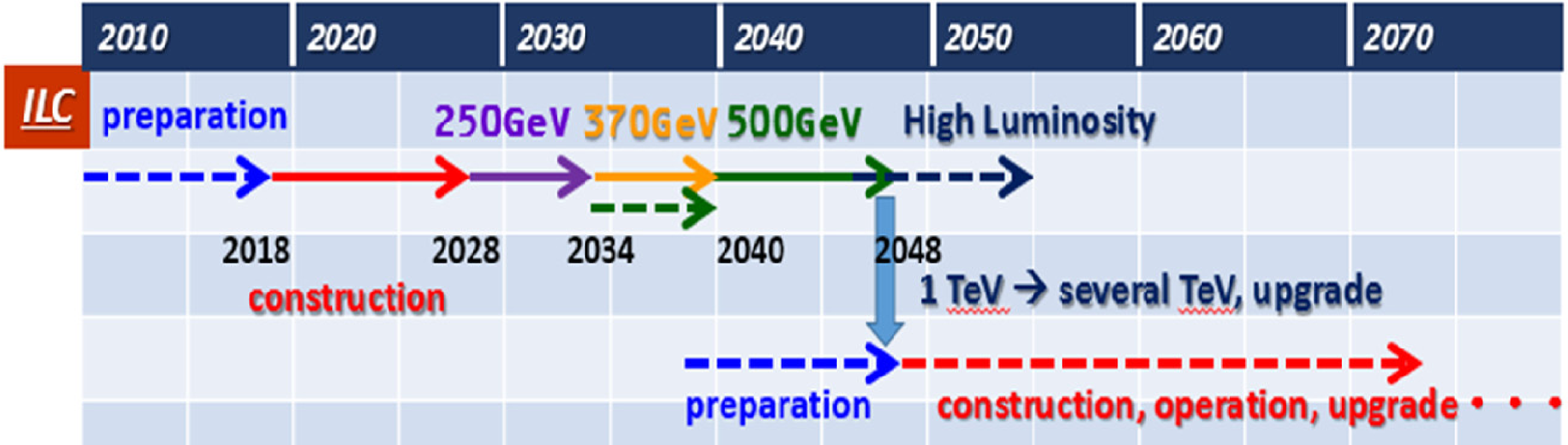
Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
E gradient in SCRF acc. cavity	31.5 MV/m +/-20% Q_0 = 1E10

2E=250-500 GeV, upgradable to 1000 GeV

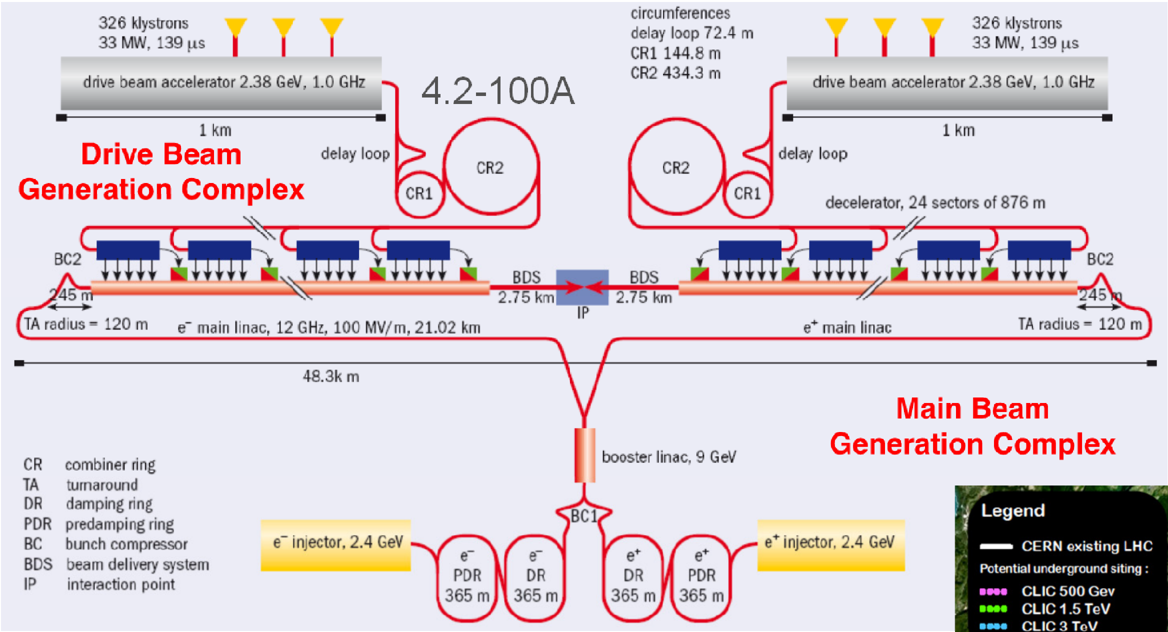
Japan is interested to host
-decision ~2018
-construction ~2019 (~10 years)
-physics ~2030

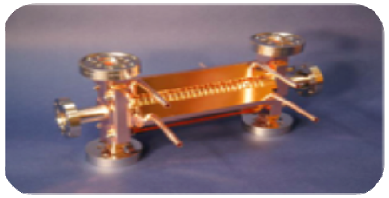
Unfortunately in this scenario the photon collider is possible here only in 40 years



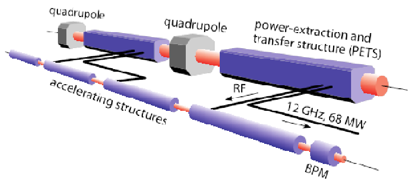


Compact LInear Collider (CLIC)

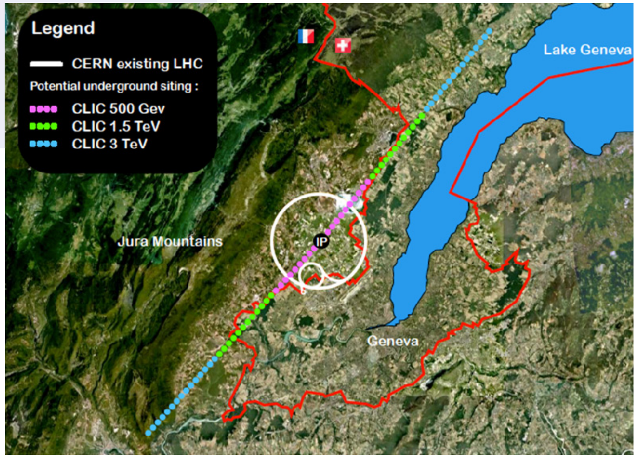




G_a ~ 100 MV/m



- CLIC
  - e+e- 500 - 3000 GeV
  - x-band accelerator technology
  - 2-beam acceleration
  - $\mathscr{L}$ ~ 2-6×10^{34}



0.5 TeV: 8,300 MCHF ($\mathcal{L}$ ~ 1.4×10^{34})

In best case construction can start in 2024-25; commissioning in ~2033.

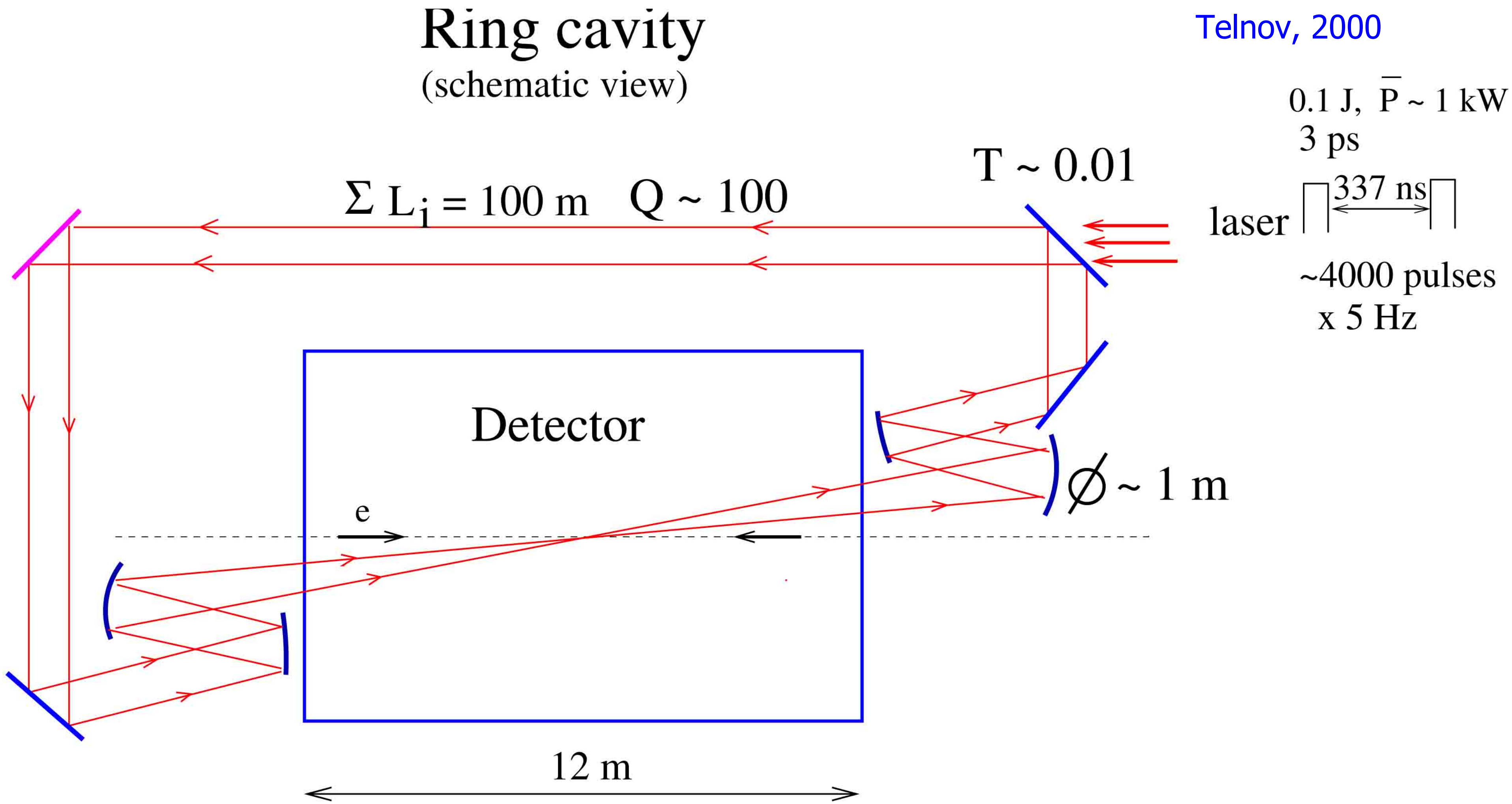
Requirements for the ILC laser system

- 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 dutation ~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

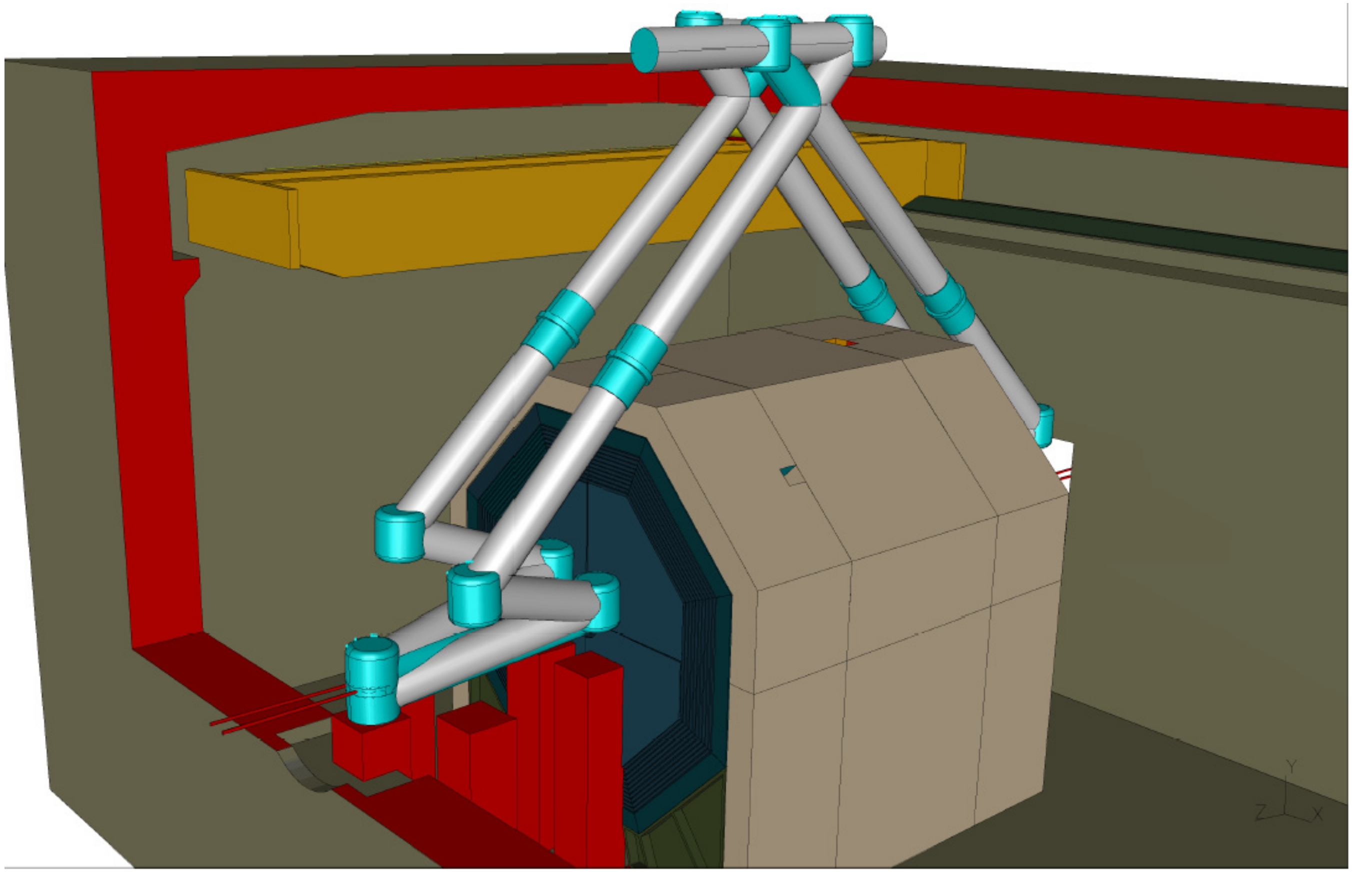


The cavity includes adaptive mirrors and diagnostics. Optimum angular divergence of the laser beam is ±30 mrad, A≈9 J (k=1), $\sigma_t \approx 1.3$ ps, $\sigma_{x,L}$~7 μm

View of the detector with the laser system

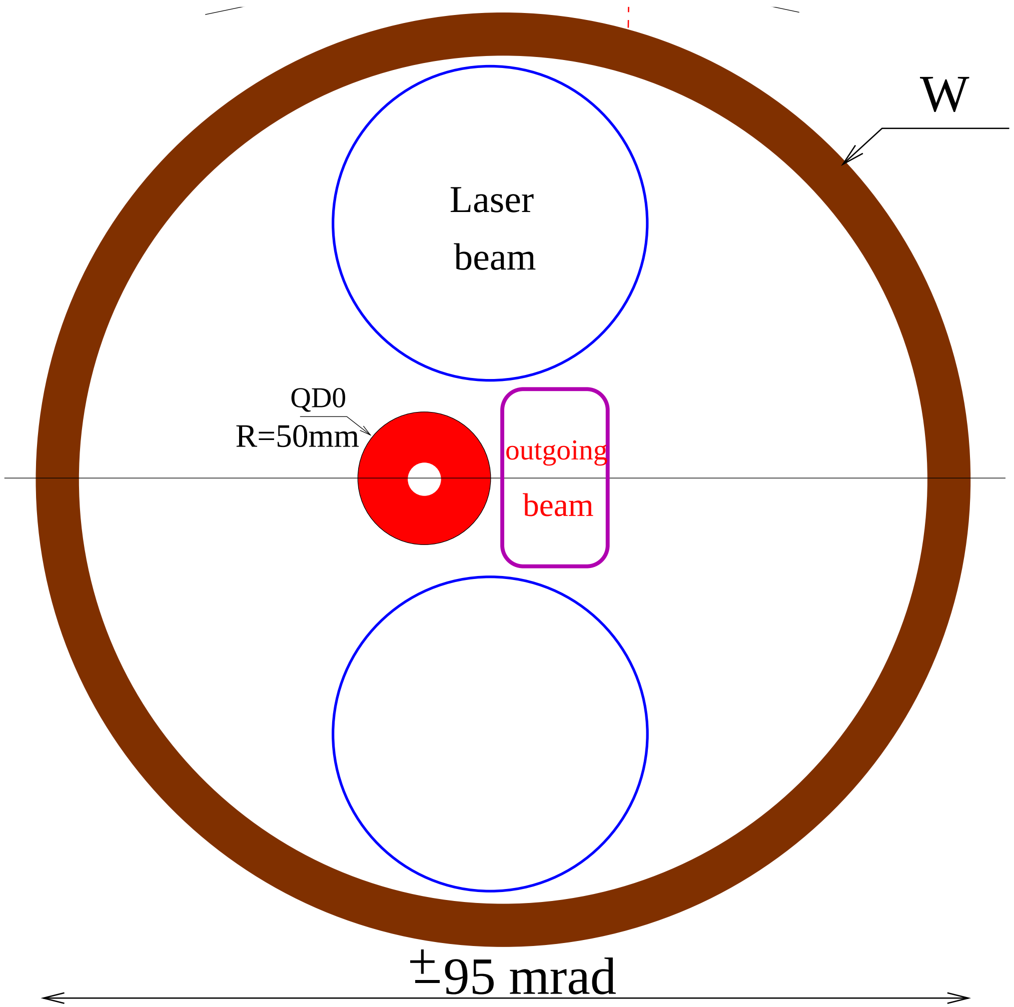
(the pumping laser is in the building at the surface)

DESY-Zeuten design (2005)



Here all mirrors are outside the detector which make life easier.
Disadvantage – too big first mirrors (d>1m).

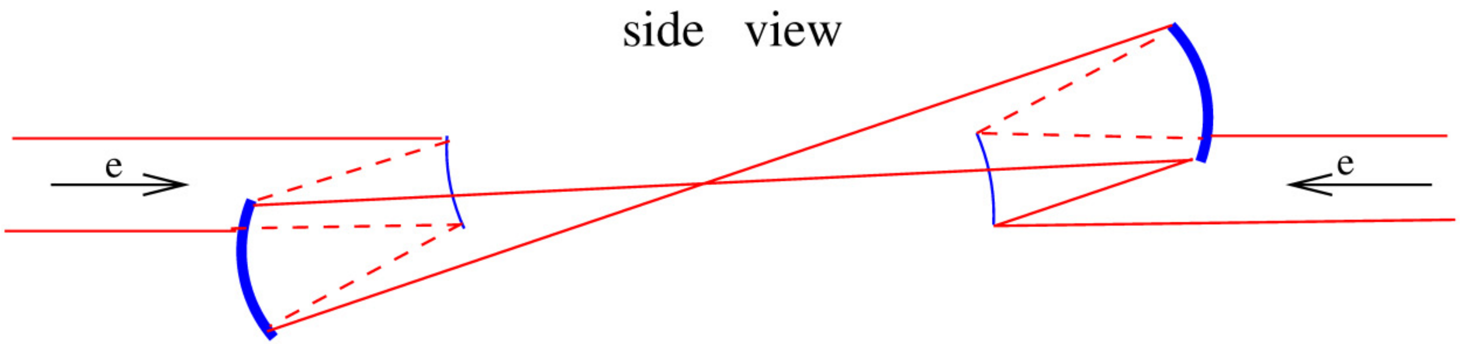
Layout of the quad, electron and laser beams at the distance 4 m from the interaction point (IP)

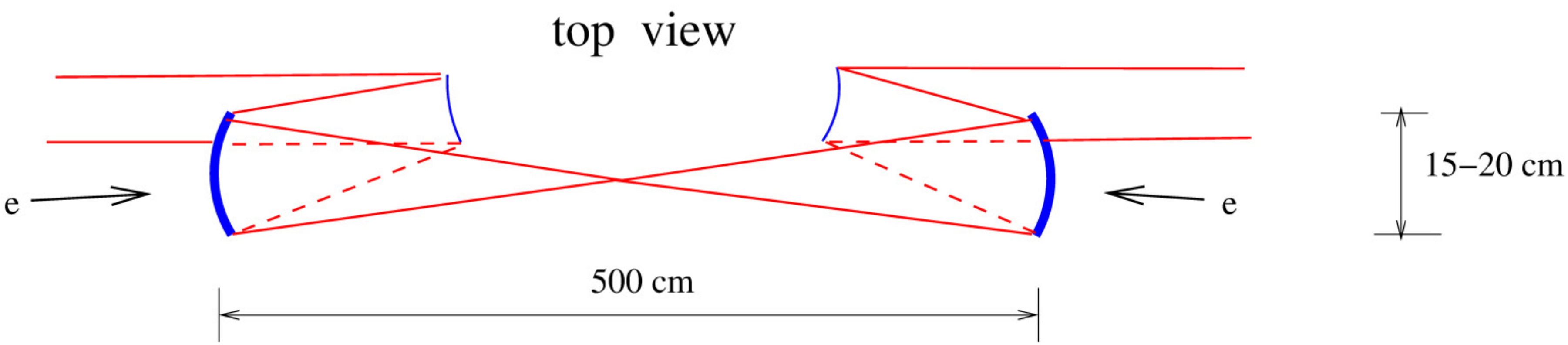


Another approach of laser optics inside the detector:

First mirrors with diameters 15 cm are placed at a distance 2-3 m from IP. In this scheme at least 4 mirrors for each of 2 lasers should be placed inside the detector in order to enter and output laser beams from the detector

below only one of two laser beams is shown

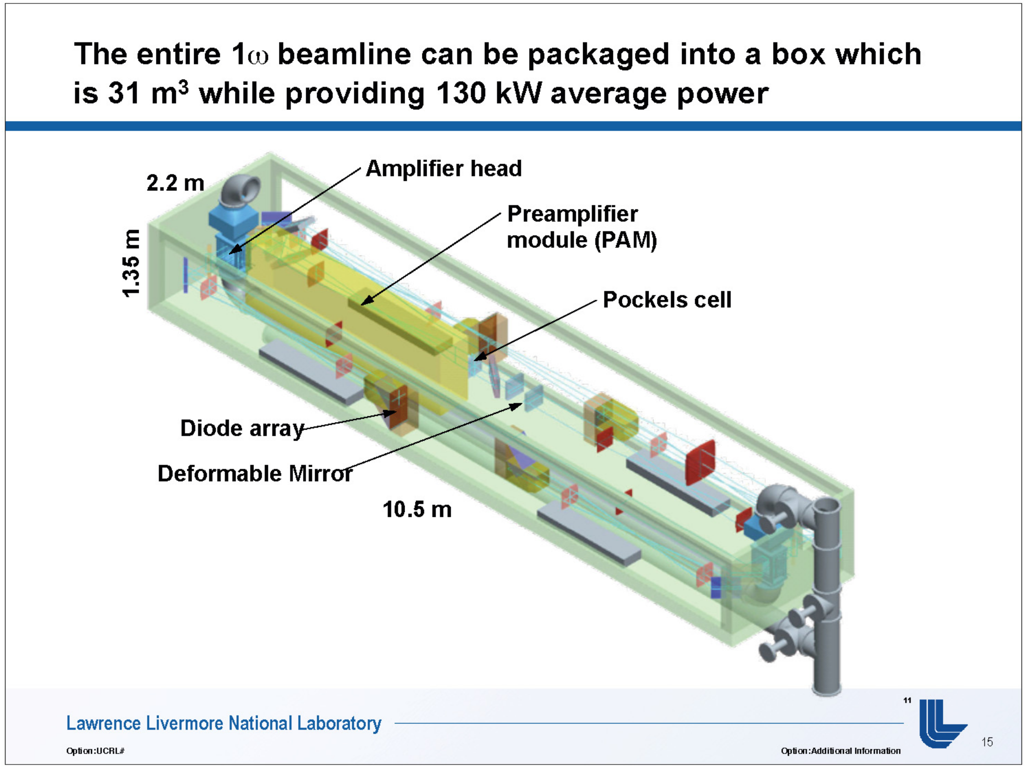




Recently new option has appeared, one pass laser system, based on new laser ignition thermonuclear facility

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

(the pulse can be split into the ILC train)



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

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, τ~1 ps
Number of bunches in one train	354
Length of the train	177 ns=53 m
Distance between bunches	0.5 ns
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).

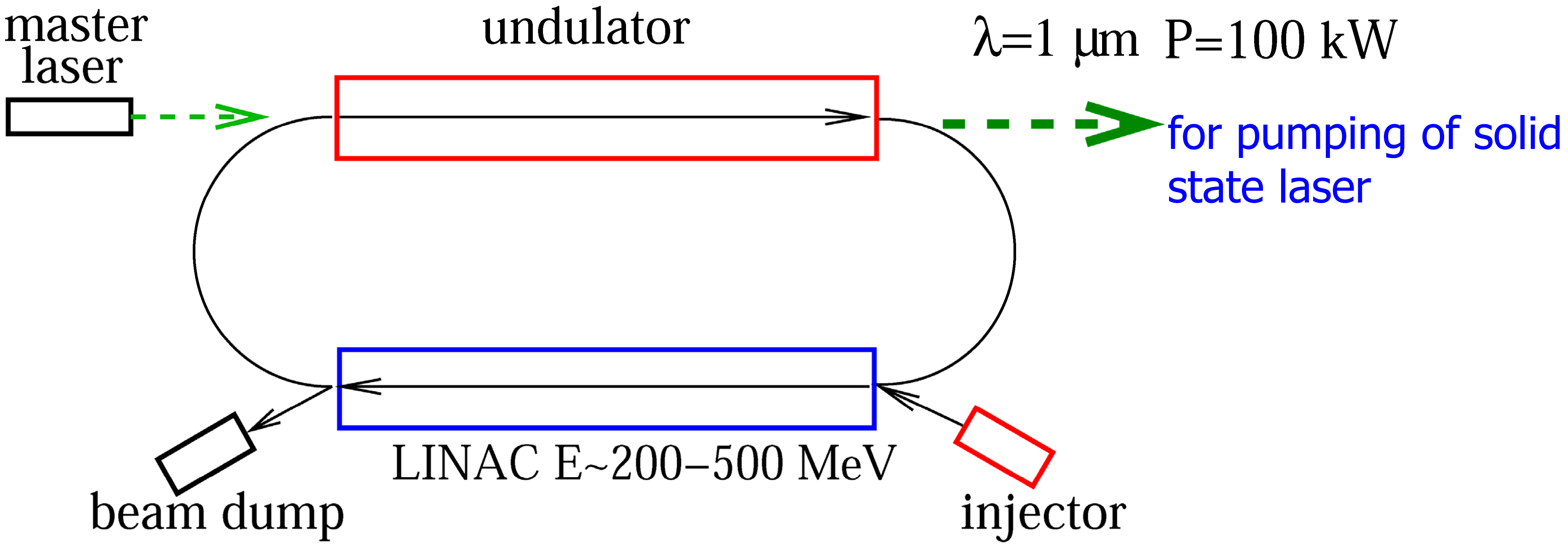
One pass laser system, developed for LIFE (LLNL) is well suited for CLIC photon collider at 2E=500 GeV.

MultiTeV CLIC needs lasers with longer wavelength: $\lambda \approx 4E_0$[TeV], μm

Another option for one pass laser (for ILC or CLIC)

to use FELs with recuperation instead of diodes for pumping of a solid state laser medium with 1 ms storage time (such as used at LIFE)

(Telnov, 2010)



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!

The discovery of the Higgs boson in 2012 has triggered several proposal of photon collider Higgs factories (without e+e-):

Photon collider Higgs factories

γγ Higgs factories appeared in 2012-2013 years

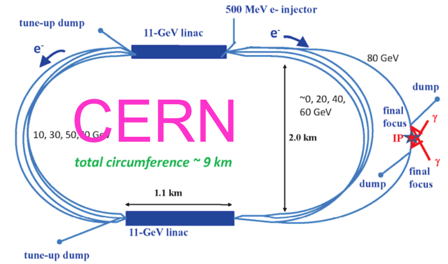
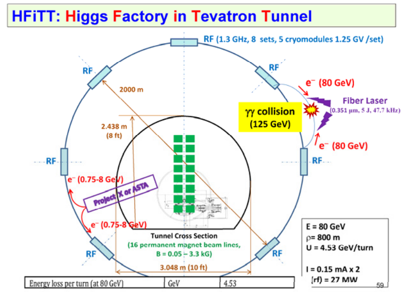


Figure 3: *Sketch of a layout for a γγ collider based on recirculating superconducting linacs – the SAPPHiRE concept.*

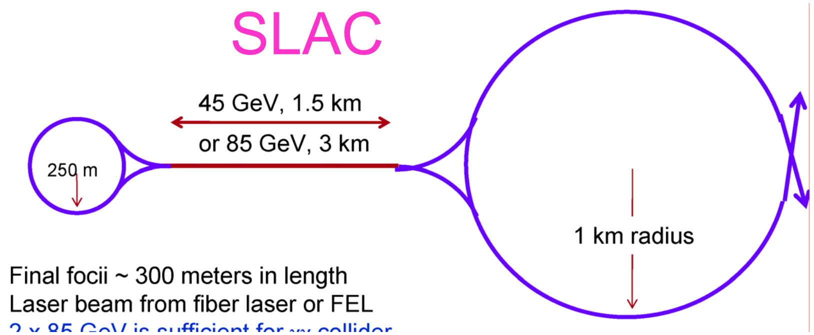


FNAL

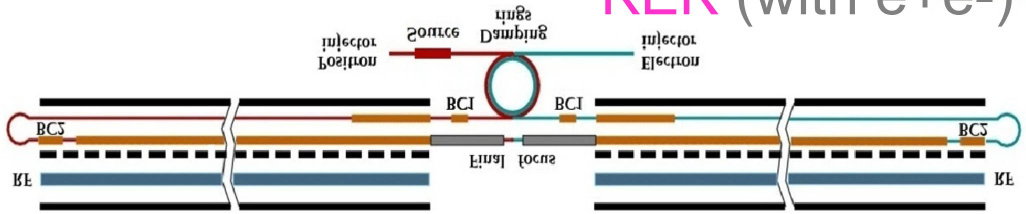
JLAB

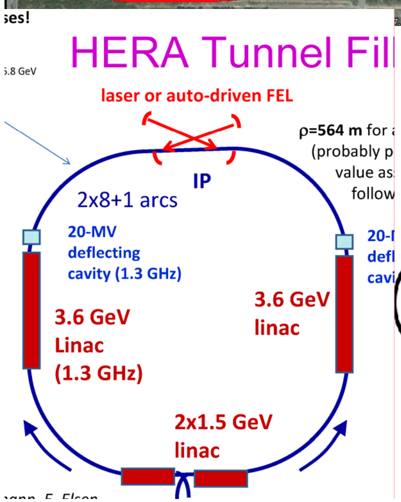
FNAL

SLAC



KEK (with e+e-)





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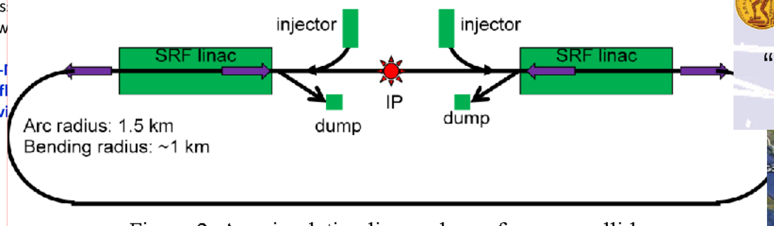


Turkey

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]

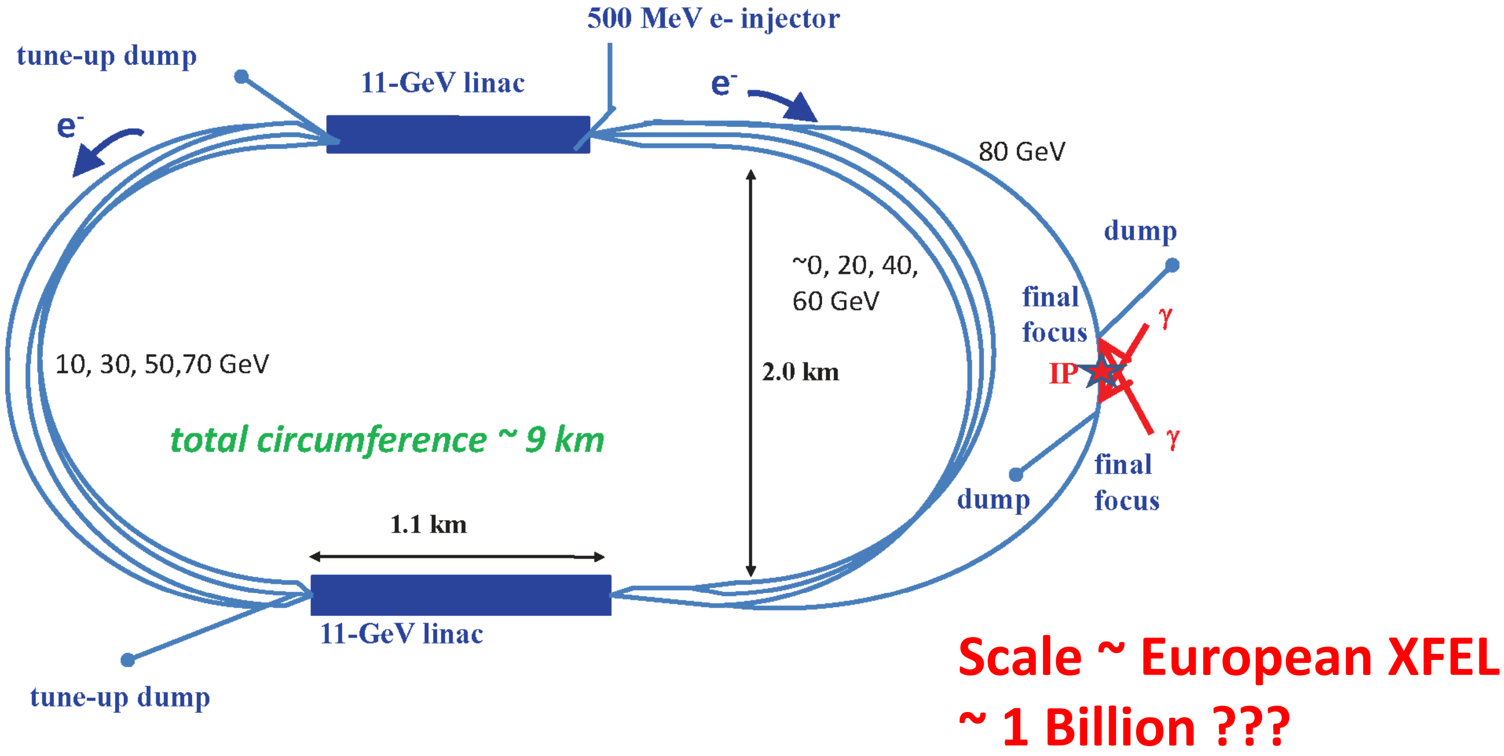


Figure 3: *Sketch of a layout for a $\gamma\gamma$ collider based on recirculating superconducting linacs – the SAPPHiRE concept.*

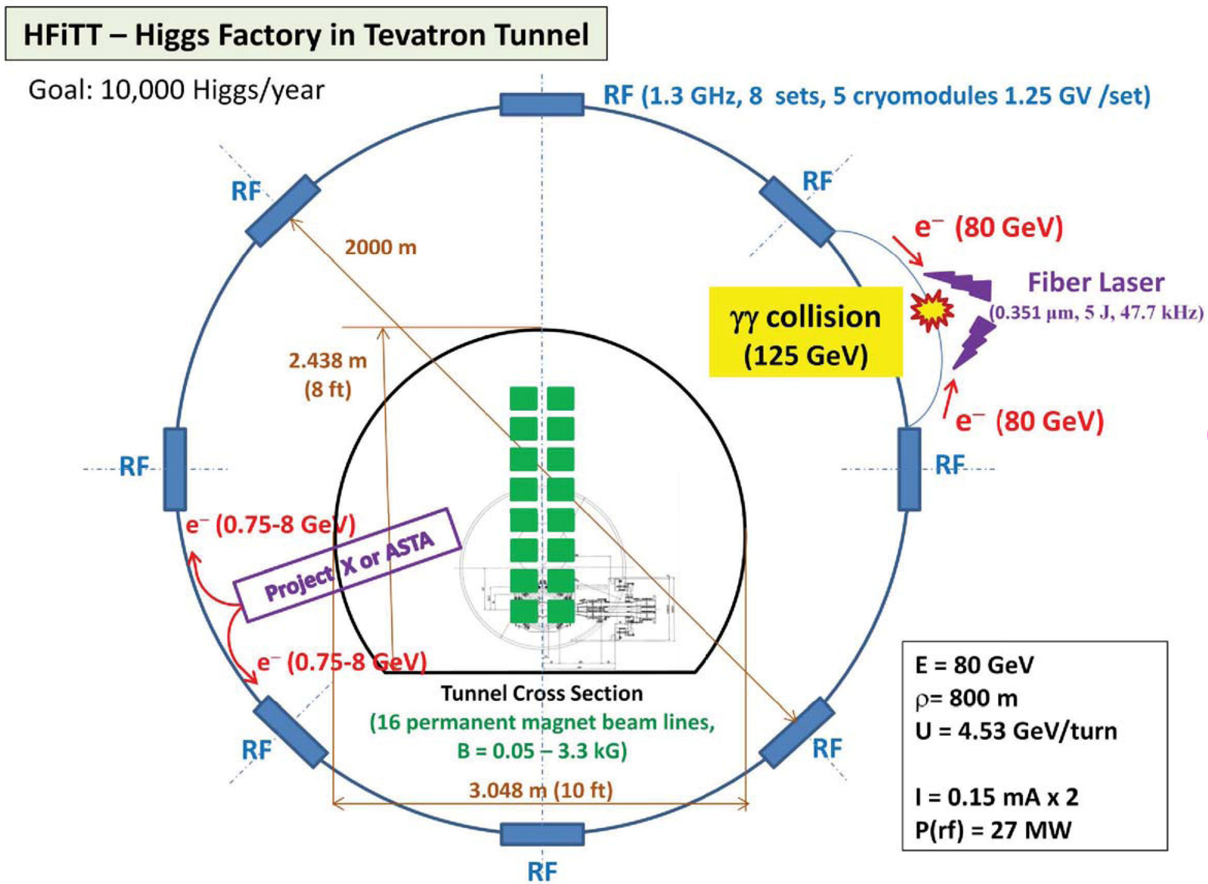
The scheme is based on LHeC electron ring, but shorter bunches and somewhat higher energy, 80 GeV

Some remarks on SAPPHIRE

- The length of the ring 9 km (2.2 km linac, 70 km ! arcs).
- The PLC with E=80 GeV and λ=1.06/3 μm (x=4.6) have too low energy final electrons, this courses very large disruption angles.
- In addition, E=80 GeV is not good for the Higgs factory. 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). But energies E>100 GeV are not possible at ring colliders like Sapphire due to unacceptable emittance dilution and the energy spread (the emittance increases proportionally to E^6/R^4). There is also a problem with dilution of the vertical emittance as (next slide).

HFiTT – Higgs Factory in Tevatron Tunnel

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



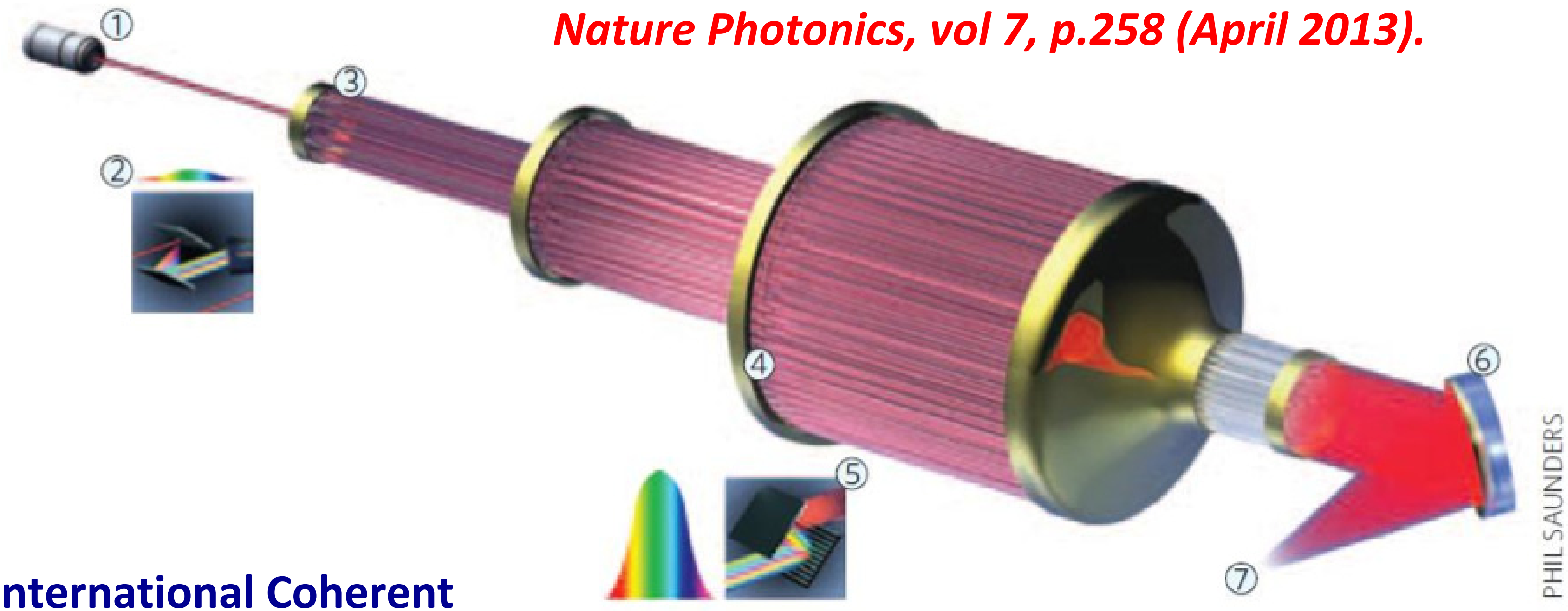
C=6 km

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 during the acceleration beams jump up and down, by about 1,5 m, 128 times! The vertical emittance will be certainly 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]

10 J, 10 kHz

Very good approach for equal spacing between bunches and problematic for collider with bunch trains, such as ILC, CLIC, because need very high diode peak power.

Plasma people also like photon collders, because acceleration of electron is much easier than positrons

TABLE II. Example parameters for a 0.5 TeV laser-plasma linear $\gamma\gamma$ collider.

Plasma number density, n_0 [cm^{-3}]	10^{17}
Beam energy, γmc^2 [TeV]	0.25
Geometric luminosity, $\mathcal{L}$ [10^{34} s^{-1} cm^{-2}]	2
Number per bunch, N [10^9]	4
Collision frequency, f [kHz]	15
Number of stages (1 linac), N_{stages}	25
Linac length (1 beam), L_{total} [km]	0.05
Total wall-plug power, P_{wall} [MW]	80
Compton scattering laser wavelength [μm]	1
Compton scattering laser energy [J]	6
Compton scattering laser duration [ps]	7
Compton scattering laser Rayleigh range [mm]	1
Compton scattering intensity [10^{18} W/cm^{-2}]	0.27
Gamma beam peak energy [TeV]	0.2
Conversion efficiency [$e \rightarrow \gamma$]	0.65

[8] W. P. Leemans, B. Nagler, A. J. Gonsalves, C. Tóth, K. Nakamura, C. G. R. Geddes, E. Esarey, C. B. Schroeder, and S. M. Hooker, Nature Phys. **2**, 696 (2006).

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[10] A. Pukhov and J. Meyer-ter-Vehn, Appl. Phys. B **74**, 355 (2002).

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[12] N. E. Andreev, L. M. Gorbunov, V. I. Kirsanov, K. Nakajima, and A. Ogata, Phys. Plasmas **4**, 1145 (1997).

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[14] X. Wang, P. Muggli, T. Katsouleas, C. Joshi, W. B. Mori, R. Ischebeck, and M. J. Hogan, Phys. Rev. ST Accel. Beams **12**, 051303 (2009).

[15] E. Cormier-Michel, E. Esarey, C. G. R. Geddes, C. B. Schroeder, W. P. Leemans, D. L. Bruhwiler, B. Cowan, and K. Paul, in Proceedings of the 10th International

Physics motivation for the photon collider at LC

(shortly, independent on a physics scenario)

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

- the energy is smaller only by 10-20%
- the number of interesting events is similar or even higher
- access to higher particle masses (H,A in $\gamma\gamma$, charged and light neutral SUSY in γe)
- higher precision for some phenomena ($\Gamma_{\gamma\gamma}$, CP-proper.)

  $\Gamma(H\rightarrow\gamma\gamma)$ width can be measured with statistics ≈ 60 times higher than in e+e- collisions.
- different types of reactions (different dependence on theoretical parameters)

It is the unique case when linear colliders allow to study new physics in several types of collisions at the cost of very small additional investments

Unfortunately, the physics in LC region is not so rich as expected, by now LHC found only light Higgs boson.

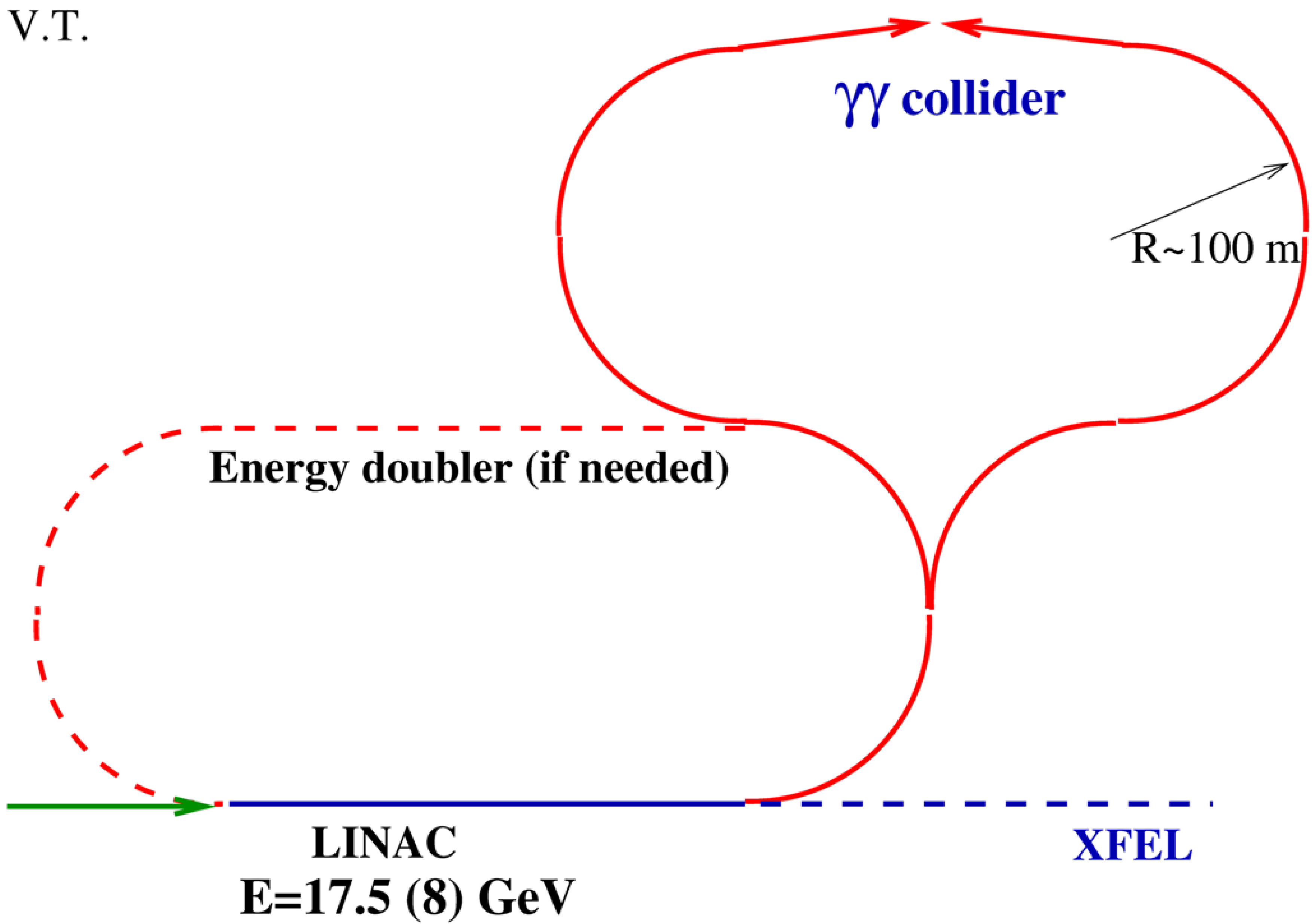
A new proposal !!!

The Photon collider based on European XFEL with $E_0 \approx 17.5$ GeV

(or other new FEL with $E_0=8$ GeV with energy doubling)

for study $\gamma\gamma$ physics in c, b quark energy region $W_{\gamma\gamma}=3\text{-}12$ GeV

Scheme of the collider

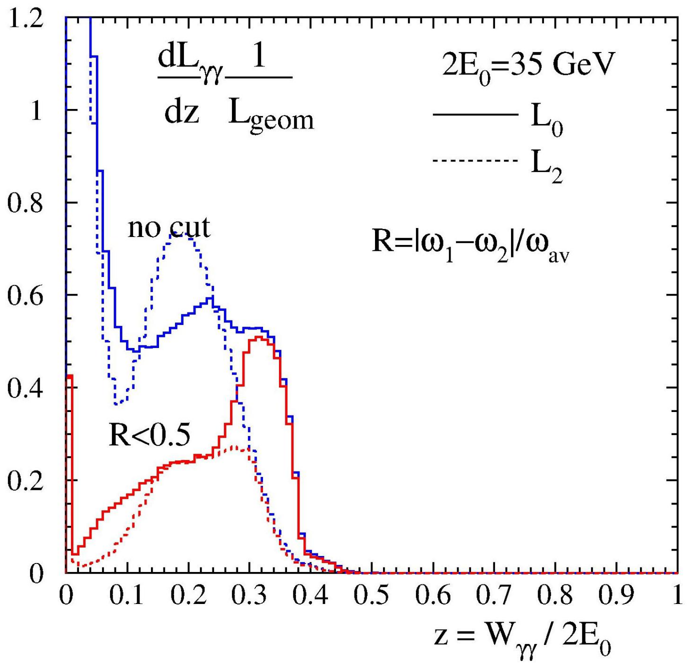


Linac not in scale

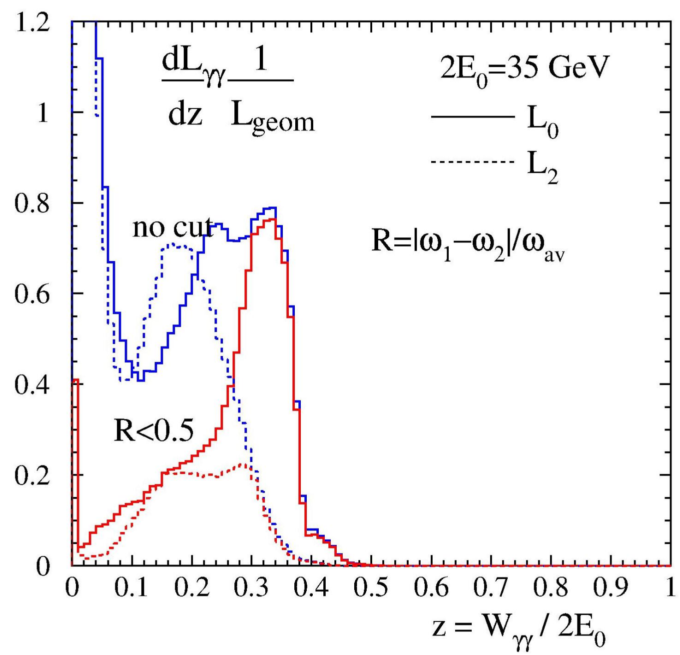
European Superconducting XFEL start operation in 2017. Its electron beam parameters: E_0=17.5 GeV, N=0.62·10^{10} (1 nQ), σ_z=25 μm, ε_n=1.4 mm mrad, f≈30 kHz

Using arcs with R~100-200 m we can get a photon collider with f=15 kHz. Other parameters for γγ collider: β^*=70 μm, σ_z=25 μm→70 μm (to reduce disruption angles), laser wavelength λ=0.5 μm, we get the following γγ luminosity spectra:

Unpolarized electrons, P_c=-1



Polarized electrons, $2\lambda_e P_c$=-0.85



L_{geom}=1.6·10^{33}

↓

L_{geom}=2.3·10^{34} (with low emittance plasma source

γγ peak at 12 GeV, covers all bb-meson region. Electron polarization is desirable, but not mandatory (improvement <1.5 times). Easy to go to lower energies by reducing the electron beam energy.

By increasing the CP-IP distance the luminosity spectrum can be made more narrow and cleaner

Resonance formation from two real photon collisions

Q = 0 , C = +, J^P= 0^+, 0^-, 2^+, 2^-, 3^+, 4^+, 4^-, 5^+ … (even)$^\pm$, (odd ≠1)$^+$

$$\vec{J} = \vec{L} + \vec{S}, \quad P = (-1)^{L+1}, \quad C = (-1)^{L+S}, \quad \text{notation} \;\; n^{2S+1}L_J$$

Example: $\gamma\gamma \to \eta_b$.

There was attempt to detect this process at LEP-2 (2E=200 GeV, L=10^{32}, but only upper limit was set.

$$N = \frac{dL_{\gamma\gamma}}{dW_{\gamma\gamma}} \frac{4\pi^2 \Gamma_{\gamma\gamma}(1+\lambda_1\lambda_2)}{M_x^2} \left(\frac{\hbar}{c}\right)^2 t$$

For our collider $\frac{dL_{\gamma\gamma} 2E_0}{dW_{\gamma\gamma} L_{ee}} \simeq 0.5$, so

$$N \sim \frac{\pi^2 \Gamma_{\gamma\gamma}(1+\lambda_1\lambda_2)}{E_0 M_x^2} \left(\frac{\hbar}{c}\right)^2 (L_{ee}t) \sim 8\cdot 10^{-27} \frac{\Gamma_{\gamma\gamma}}{E_0 M_x^2 [\text{GeV}^2]} (L_{ee}t)$$

For $\Gamma_{\gamma\gamma}(\eta_b) = 0.5 \text{ keV}, E_0 = 17.5 \text{ GeV}, \text{M}(\eta_b) = 9.4 \text{ GeV}, \lambda_{1,2} = 1, L_{ee} = 1.6\cdot 10^{33} - 2.3\cdot 10^{34},$

$t = 3\cdot 10^7 s$ we get N(η_b) ≈ $1.5\cdot 10^5$ - $2\cdot 10^6$ and measure its $\Gamma_{\gamma\gamma}$

Production rate is higher than was at LEP-2 (in central region) ~ 700 - 10^4 times!

Such photon collider has very rich physics, incl. 4-quark (or molecular) states. Many such states with unclear nature have been discovered recently in c-quark and b-quark regions (X,Y,Z,X′,X″).

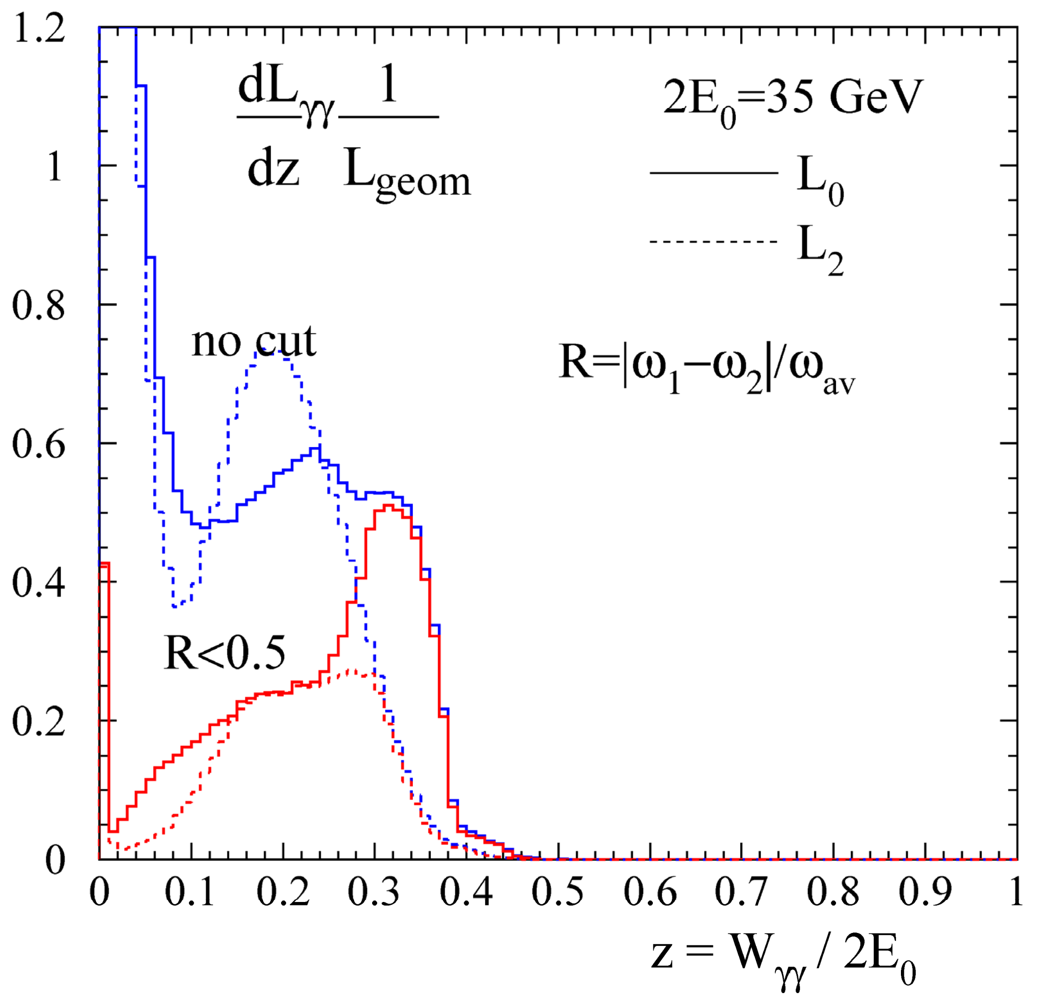
Just for information. η_b is detected in radiative decays of ϒ(nS). Babar has detected ~ 30000 η_b, this was not sufficient to detect its decay to γγ, because Br~$7\cdot 10^{-5}$. Such decay can be observed at Super-B.

Parameters of photon collider for bb-energy region (W<12 GeV)

E_0, GeV	17.5
$N/10^{10}$	0.62
f, kHz	15
σ_z, μm	70
$\varepsilon_{nx}/\varepsilon_{ny}$, mm mrad	0.1/0.1
β_x/β_y, μm	70/70
σ_x/σ_y, nm	14/14
laser λ, μm	0.5
laser flash energy, J	3 (ξ^2=0.05)
f#, τ, ps	27, 2
crossing angle, mrad	~30
b, (CP-IP dist.), mm	0.5
L_{ee}, 10^{34}	2.3
$L_{\gamma\gamma}(z>0.5z_m)$, 10^{34}	0.3
$W_{\gamma\gamma}$(peak), GeV	12

V. Telnov

Unpolarized electrons, P_c=-1



In Table a low emittance plasma gun is assumed. With the XFEL gun the luminosity is smaller 14 times.

Polarization

Gamma beams have high degree of circular or linearly polarization at maximum energies, which allow to measure simply S and P-parity of resonances (C=+)

Absence of e+e- background

At e+e- colliders, after emission of ISR e+e- can produce C=- resonances which looks similar to $\gamma\gamma$ resonances.

At e-e- based $\gamma\gamma$-collider there are no such backgrounds

$c\bar{c}$

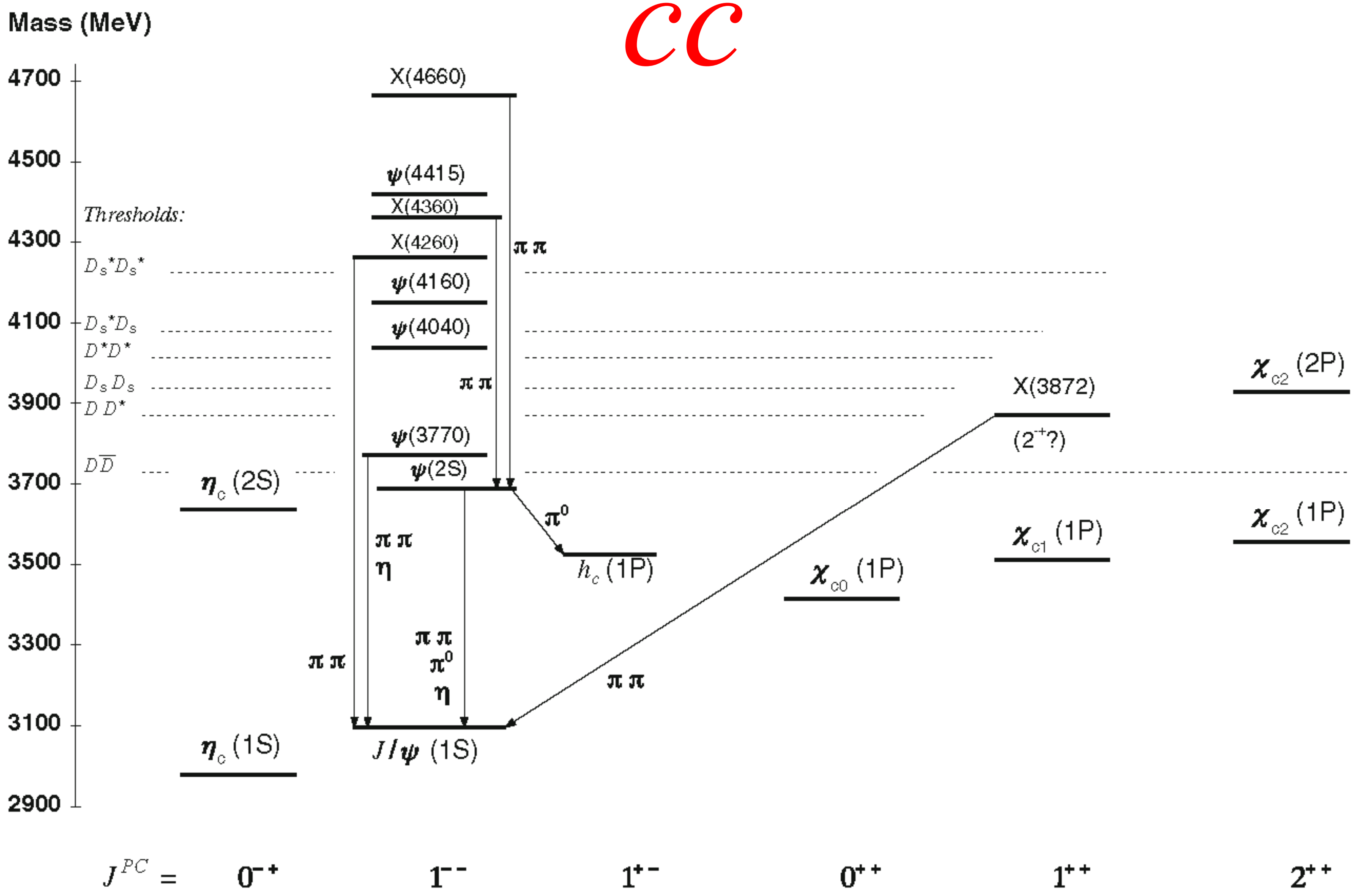


Fig. 2.1 The experimentally observed charmonium states. The states labelled X, the nature of which is unknown, are not thought to be conventional charmonium states. Figure from Ref. [1]

Almost all charmonium states below DD threshold have been observed experimentally, but there exotic X,Y,Z,X′,X″states, its $\Gamma_{\gamma\gamma}$ can help to understand its nature.

$b\bar{b}$

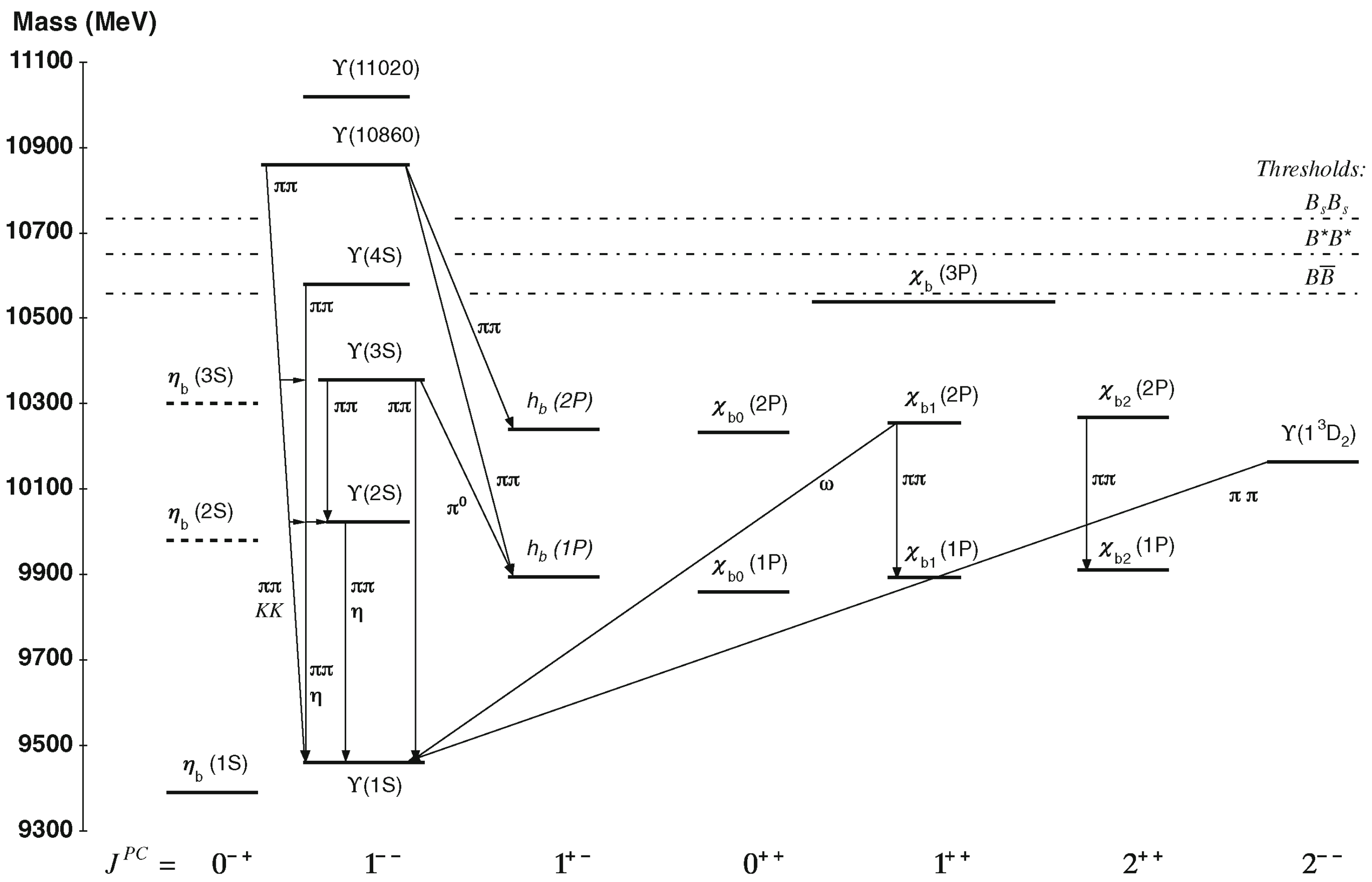


Fig. 2.2 The experimentally observed and theoretically expected bottomonium states. *Dashed lines* denote unobserved or unconfirmed states (an unconfirmed experimental candidate for the $\eta_b(2S)$ state has been observed by the Belle experiment [6]). Figure from Ref. [1]

Majority of bottomonium states below BB threshold have been observed experimentally, with exception of $\eta_b(3S)$, $h_b(3P)$ and most D-wave bottomonium. Many exotics states are observed (4-quark, molecules ??)

At e+e- colliders C+ states above DD and BB threshoulds are not observed yet because they are detected in radiative decays of Ψ and Υ, which become broad above the threshould (and radiation branching becomes very small).

In γγ-colliisons these resonances will be produced directly. Their increased total width does not influence the production rate in γγ.

Comparison of the γγ factory and LHC for study γγ-physics in *bb* region

At γγ factory $$\frac{dL_{\gamma\gamma}}{dW} \approx \frac{0.015 L_{ee}}{\text{GeV}}$$

At LHC $$\frac{dL_{\gamma\gamma}}{dW} \approx \frac{0.0025\,\Delta\eta}{W} L_{pp} \approx \frac{0.0002\Delta\eta}{\text{GeV}} L_{pp} \sim 3\cdot 10^{-4} L_{pp} \quad \text{for } \Delta\eta = 1.5$$

$$\frac{(dL/dW)_{\gamma\gamma-factory}}{(dL/dW)_{LHC}} \sim 50\frac{L_{ee}}{L_{pp}}$$

Conclusion

- Photon colliders have sense as a very cost effective addition for e+e- linear colliders. However perspectives of high energy LCs are still unclear already many years and photon collider is considered as the second stage, so can appear in ~30-40 year, at best.

- Photon collider needs high rep. rate electron linacs and powerful high rep. laser, both technology already exist. All aspects of photon collider are understood at good level. It has sense, for beginning, to consider construction of the photon collider on the energy $W_{\gamma\gamma} \leq 12$ GeV (b,c regions). Physics here is very rich, super-B factory can not study gamma-gamma physics in bb region.

  This facility (SC linac) can be used simultaneously for XFEL. So, such project has a strong motivation. This can be done on the base of existing European XFEL or (may be easier) to construct a new one in Asia or USA.