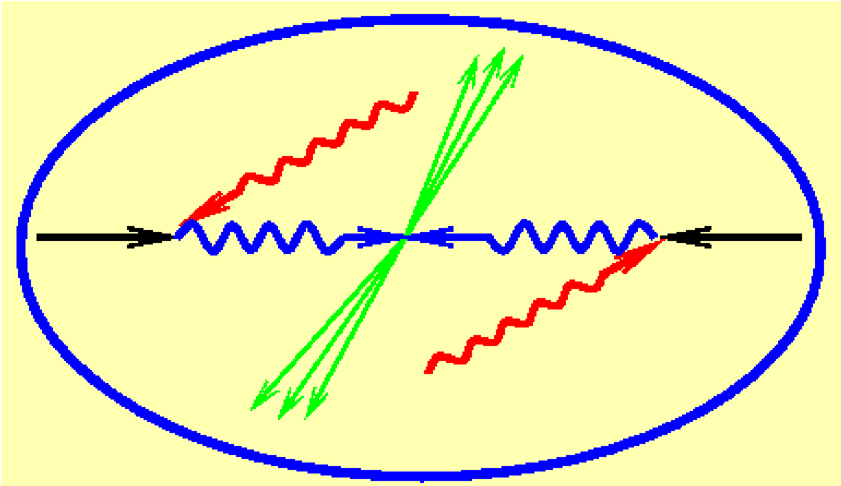

# γγ collider for bb (<12 GeV) energy region


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Budker INP and Novosibirsk State Univ.


POSIPOL'17, Budker INP, Sept 20, 2017

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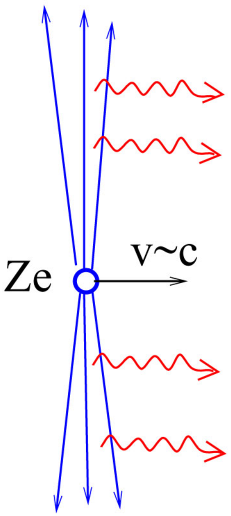
- Introduction to $\gamma\gamma$, $\gamma e$ colliders
- Projects of high energy photon colliders (ILC, CLIC)
- Circular photon collider (remarks)
- Proposal of the $\gamma\gamma$ collider for c-b quark region
- Conclusion

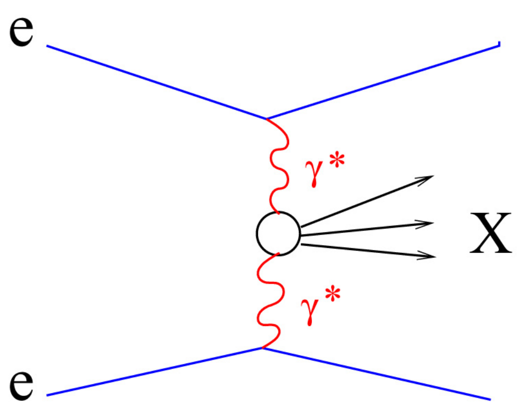
# Prehistory: colliding $\gamma^*\gamma^*$ photons

($\gamma^*$ -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

$$X = e^+e^-, \mu^+\mu^-, ...\eta'(960)..., \text{ any C+ resonances}$$

$$m_\gamma \geq m_e/\gamma$$ - almost real

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

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

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

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

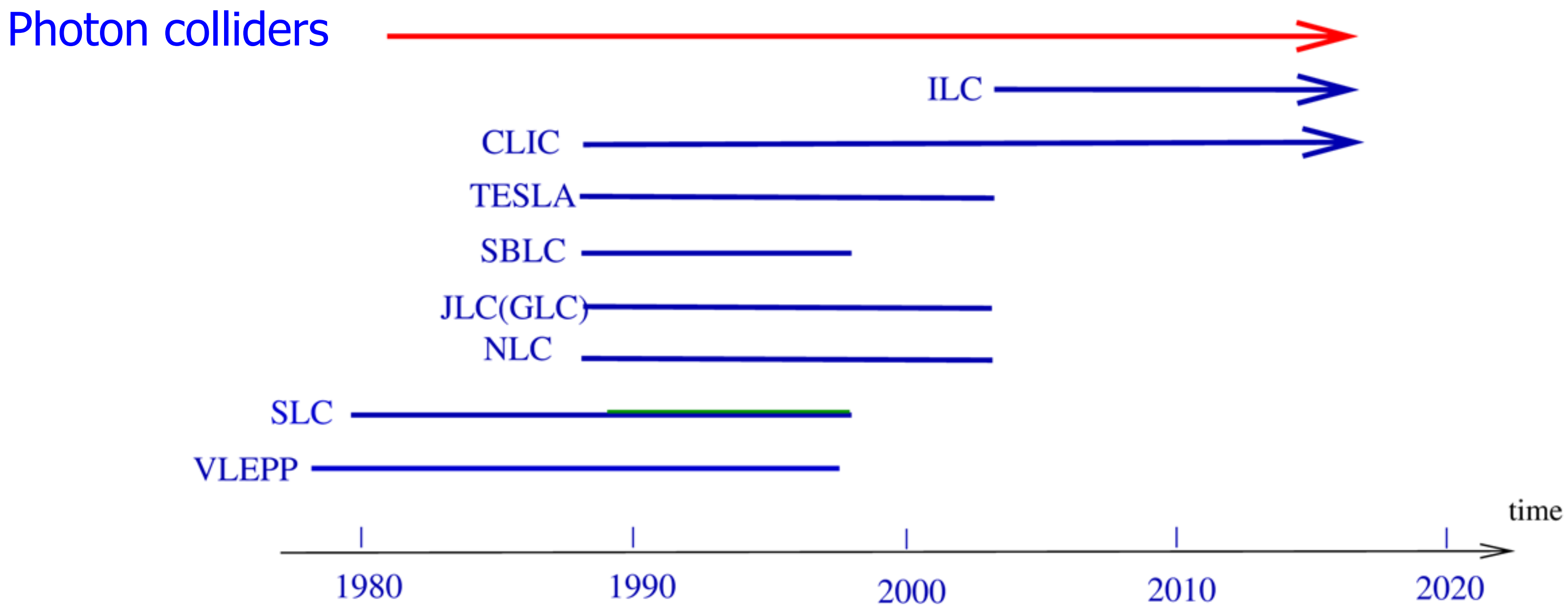
$L_{\gamma\gamma}(z>0.5) \sim 0.4 \cdot 10^{-3}\, L_{e+e-}$

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

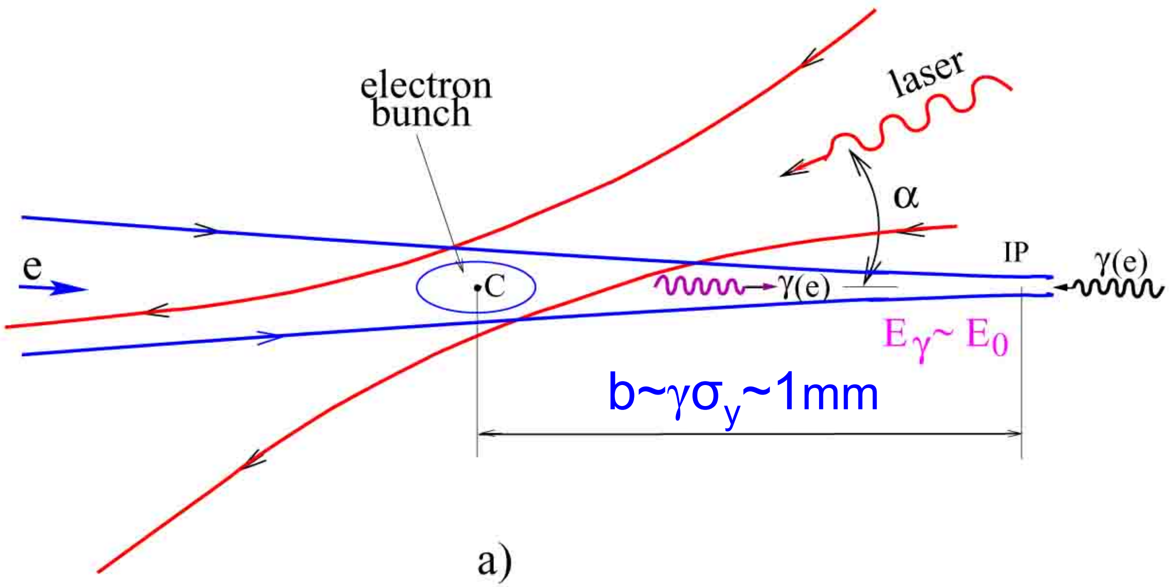
The idea of the high energy photon collider was proposed at the first workshop on physics at linear collider VLEPP (Novosibirsk,Dec.1980) and is based on the fact that at linear $e^+e^-$ ($e^-e^-$) colliders electron beams are used only once which makes possible to convert electron beam to high energy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

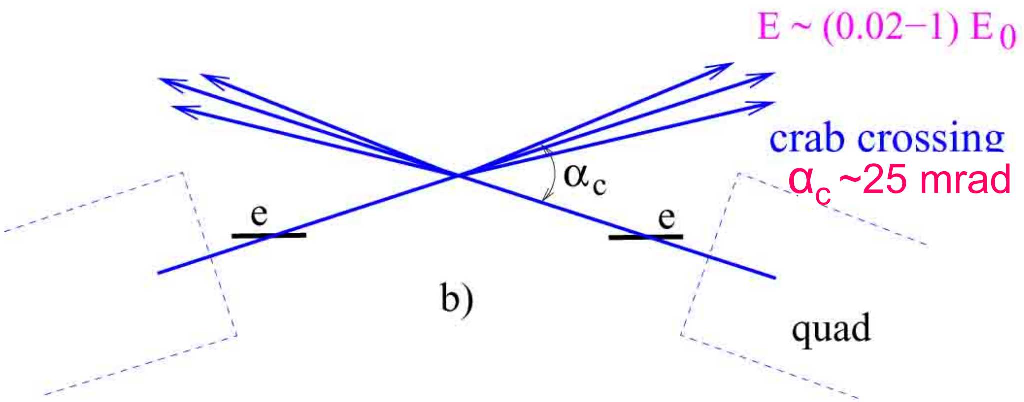
The best way of $e \to \gamma$ conversion is the Compton scattering of the laser light off the high energy electrons (laser target). Thus one can get the energy and luminosity in $\gamma\gamma$, $\gamma e$ collisions close to those in e+e- collisions: $E_\gamma \sim E_e$ ; $L_{\gamma\gamma} \sim L_{e\text{-}e\text{-}}$

## Linear colliders (projects)



# Scheme of $\gamma\gamma$, $\gamma e$ collider




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

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

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

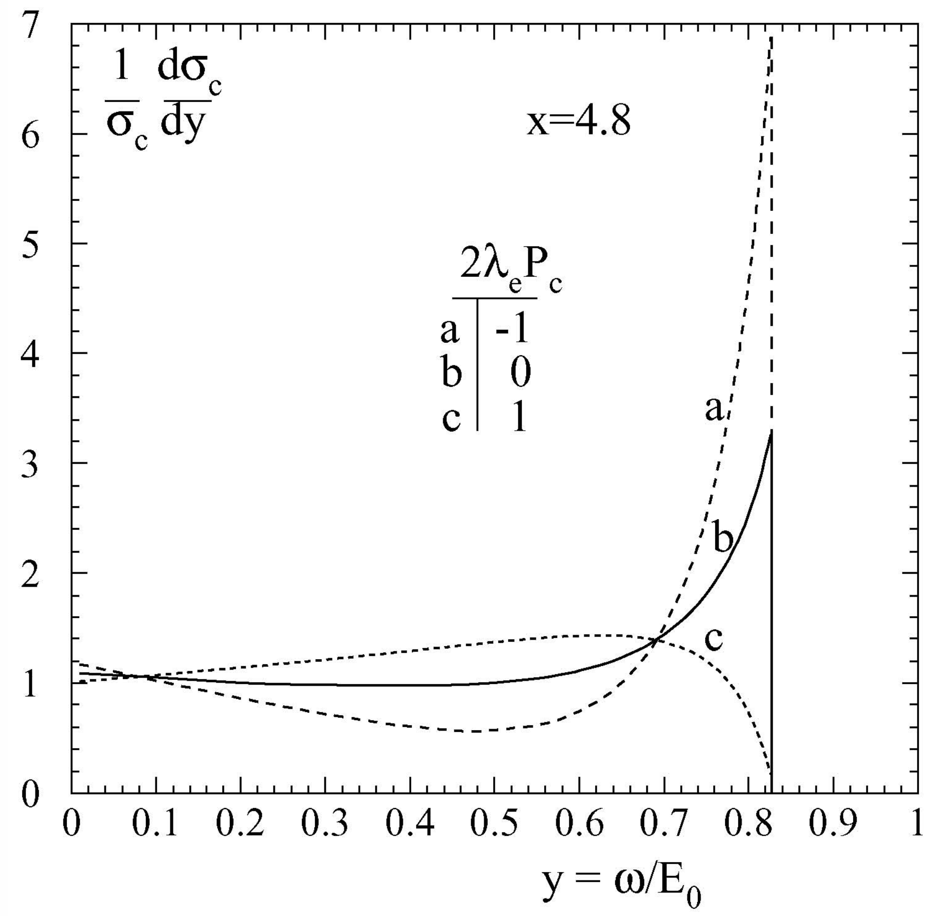
$x = 4.8$ is the threshold for
$\gamma\gamma_L \to e^+e^-$ at conv. reg.

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

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

# Electron to Photon Conversion

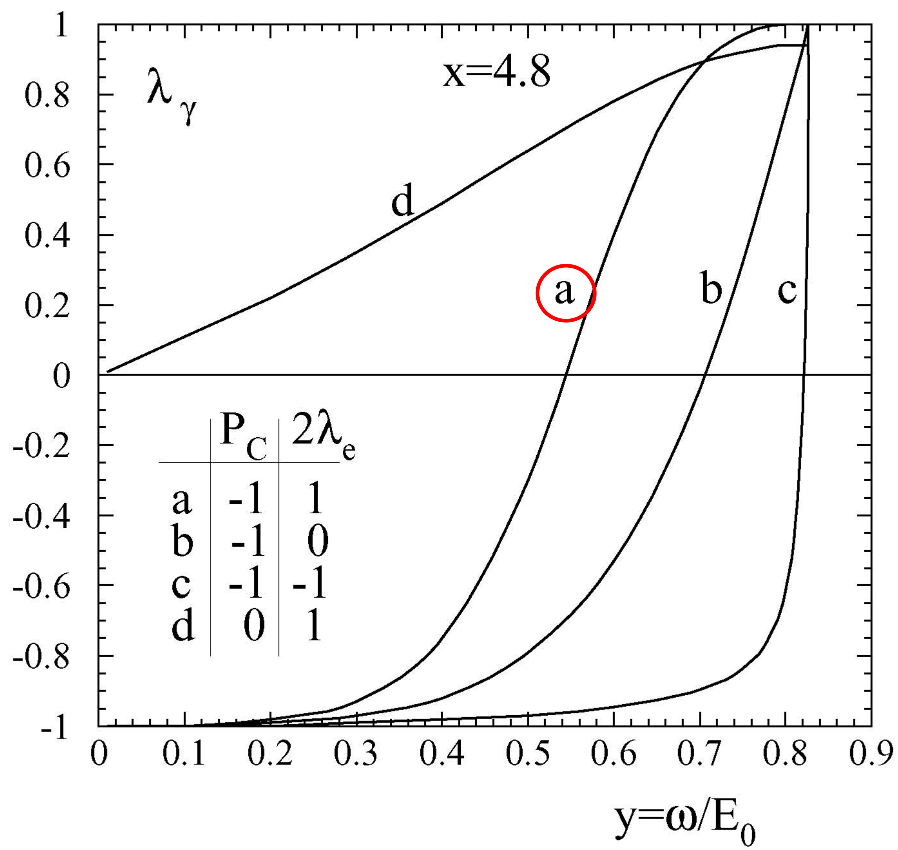
## Spectrum of the Compton scattered photons




$\lambda_e$ – 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 $\lambda_\gamma \approx 1$)

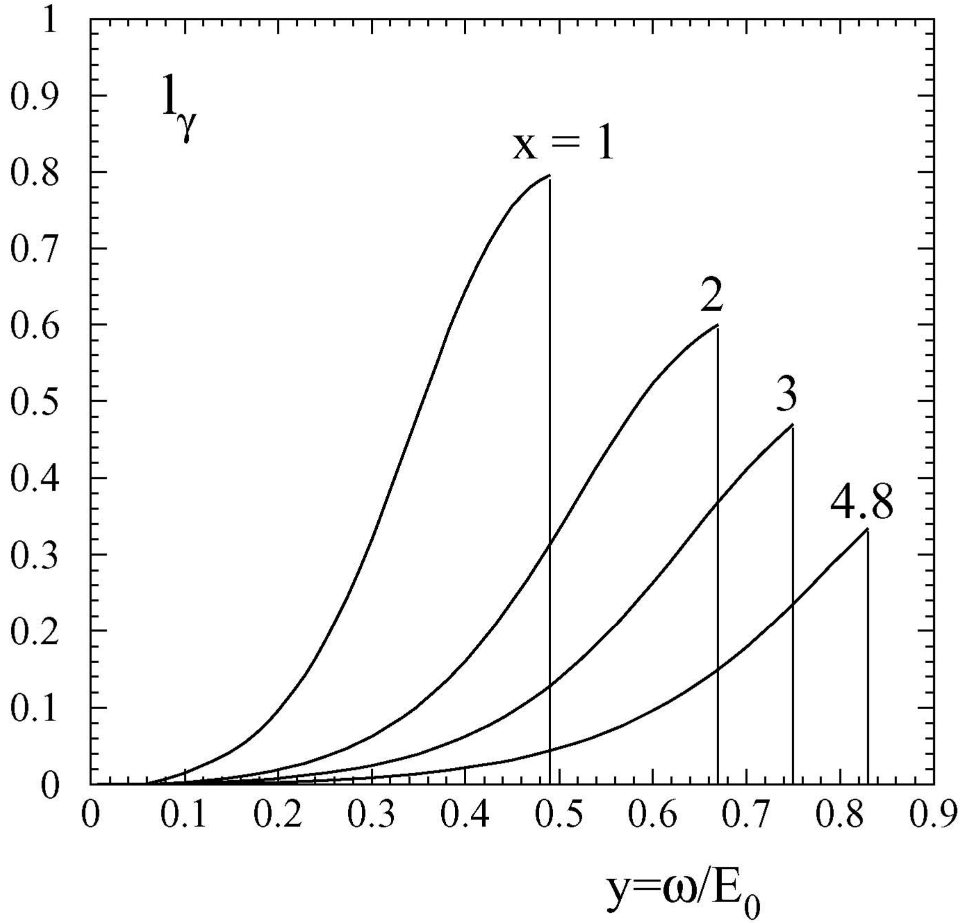
The cross section of the Higgs production

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

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

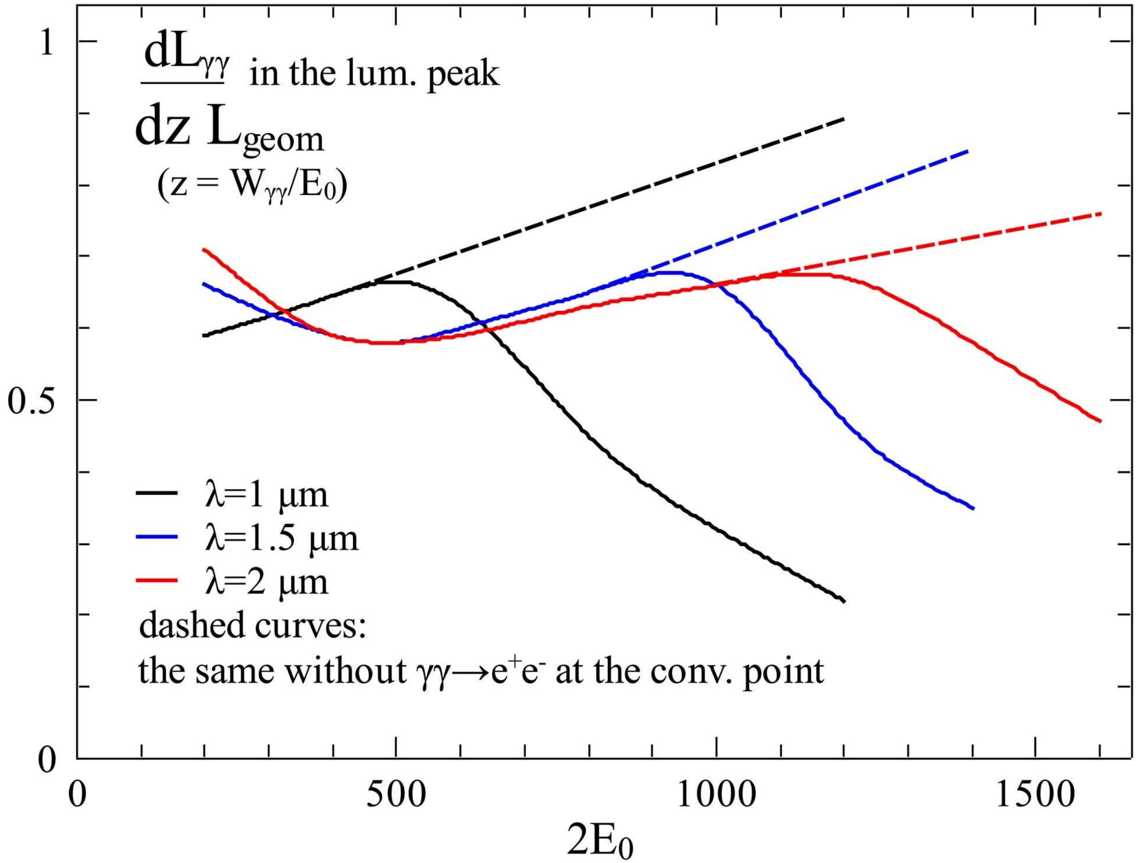
# The optimum laser wavelength

The maximum energy of photons after the Compton scattering

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

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

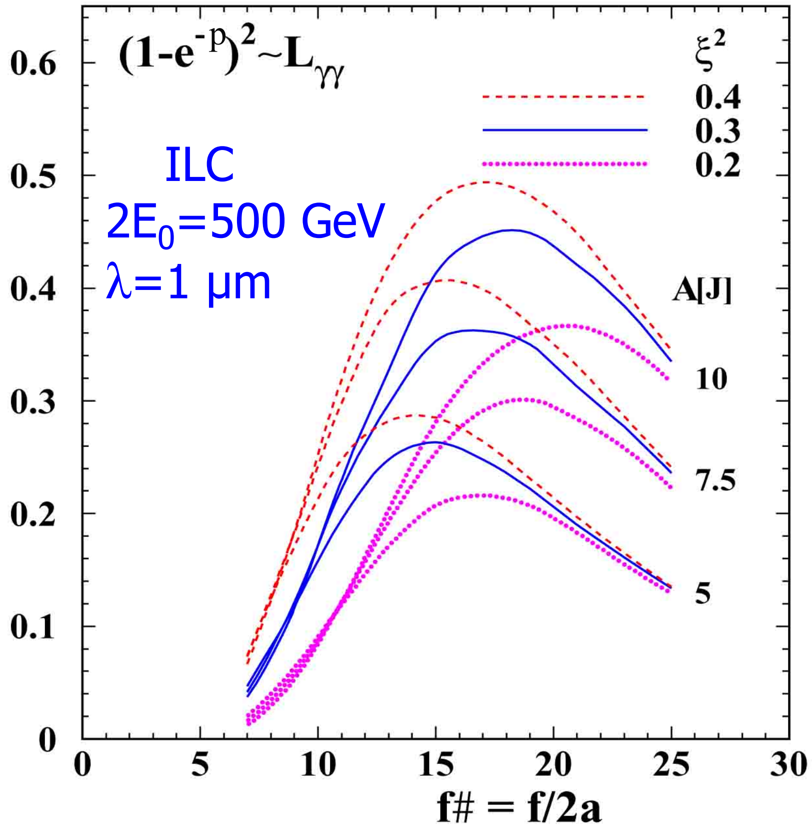
For e→γ conversion one needs thickness (t) of laser target equal about one Compton collision length ($p=t/\lambda_C \sim 1$). The required flash energy is determined by $\sigma_c$, geometric properties of laser and electron beams and by nonlinear effects in Compton scattering described by parameter $\xi^2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



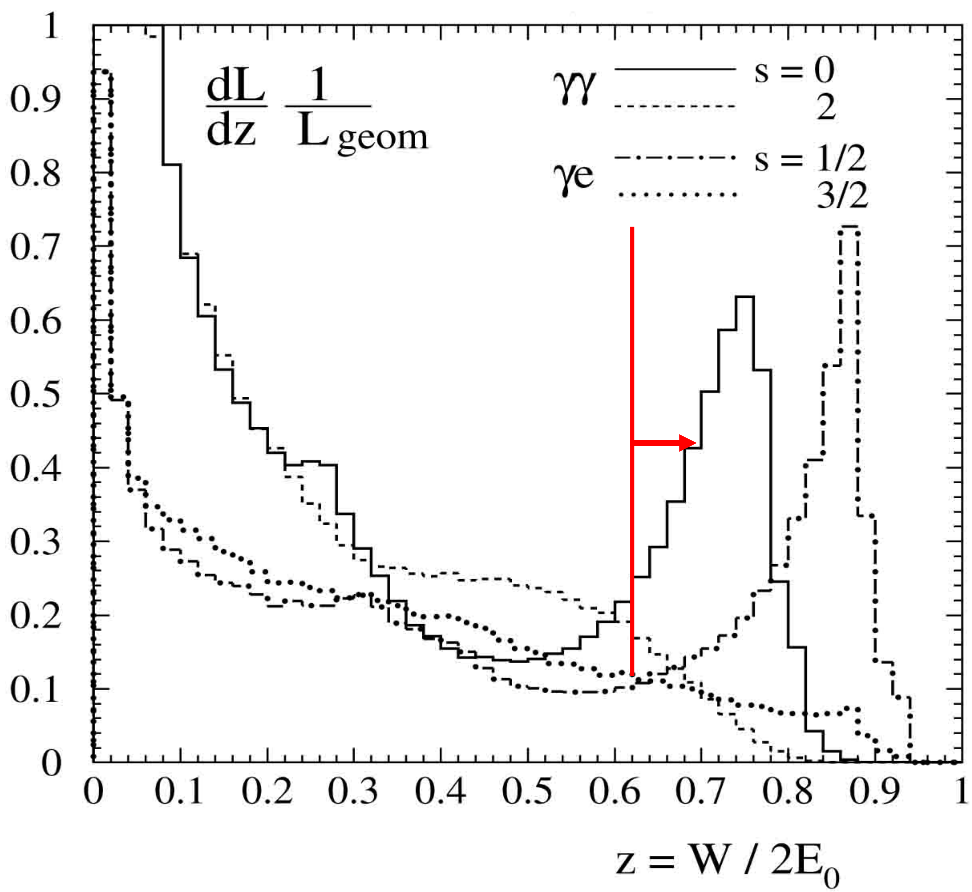

For λ=1 μm ($2E_0$=500 GeV) the required flash energy is about A~10 J and it increases for larger λ (or $E_0$) due to the nonlinear effect.
It is determined by laser diffraction and geometric beam parameters at short λ and by nonlinear effects at large λ (multiTeV collider).

# Typical $\gamma\gamma$, $\gamma e$ 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)

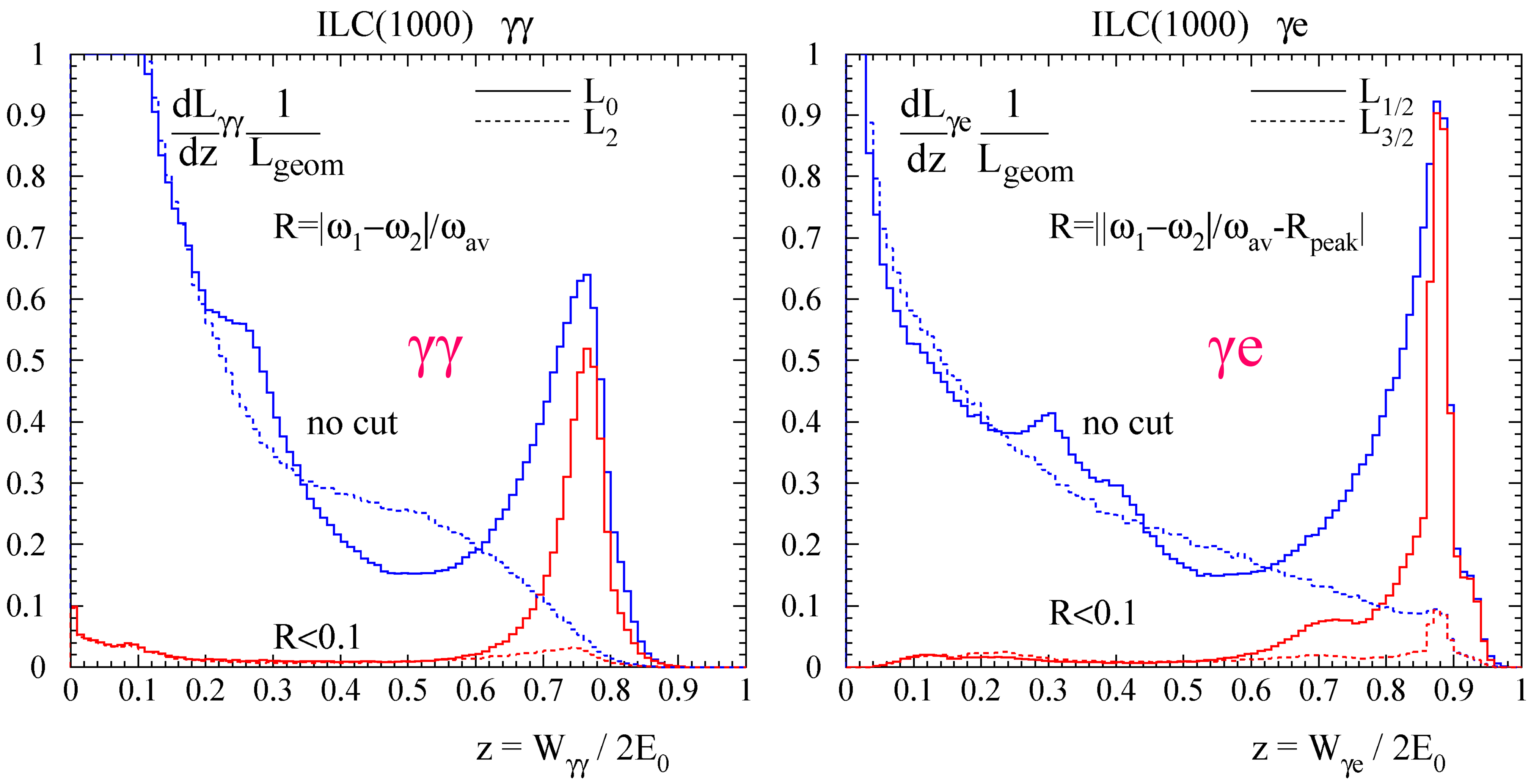



Luminosity spectra and their polarization properties can be measured using QED processes

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

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

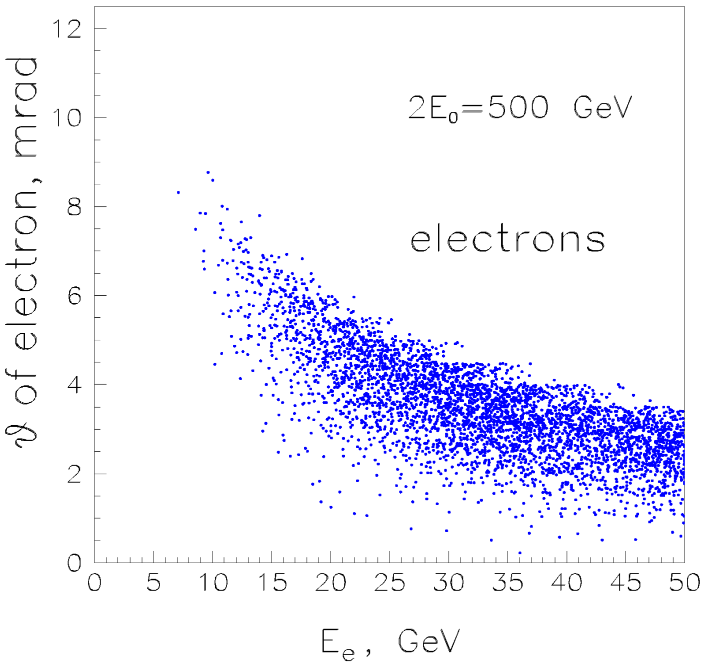
(red curves with restriction on longitudinal momentum of produced system)



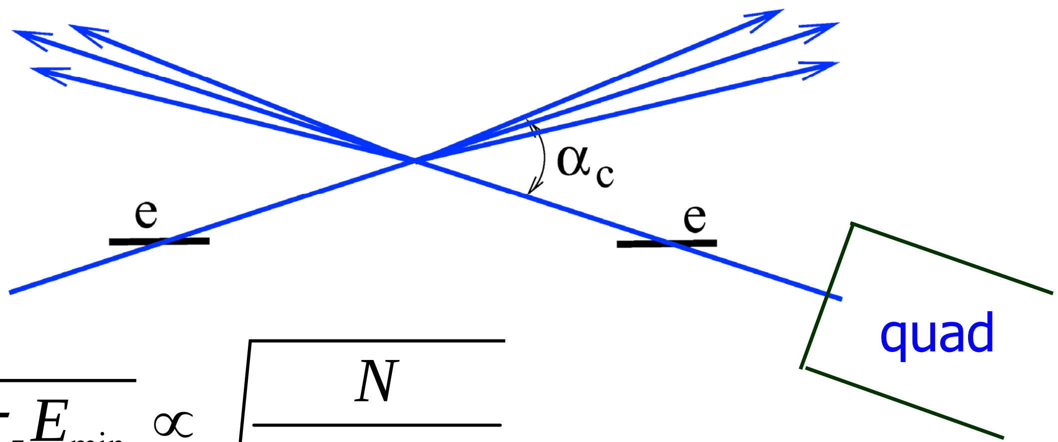

Such γγ collider would be the best option for study of X(750)

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

# Removal of disrupted beams, crossing angle, beamdump



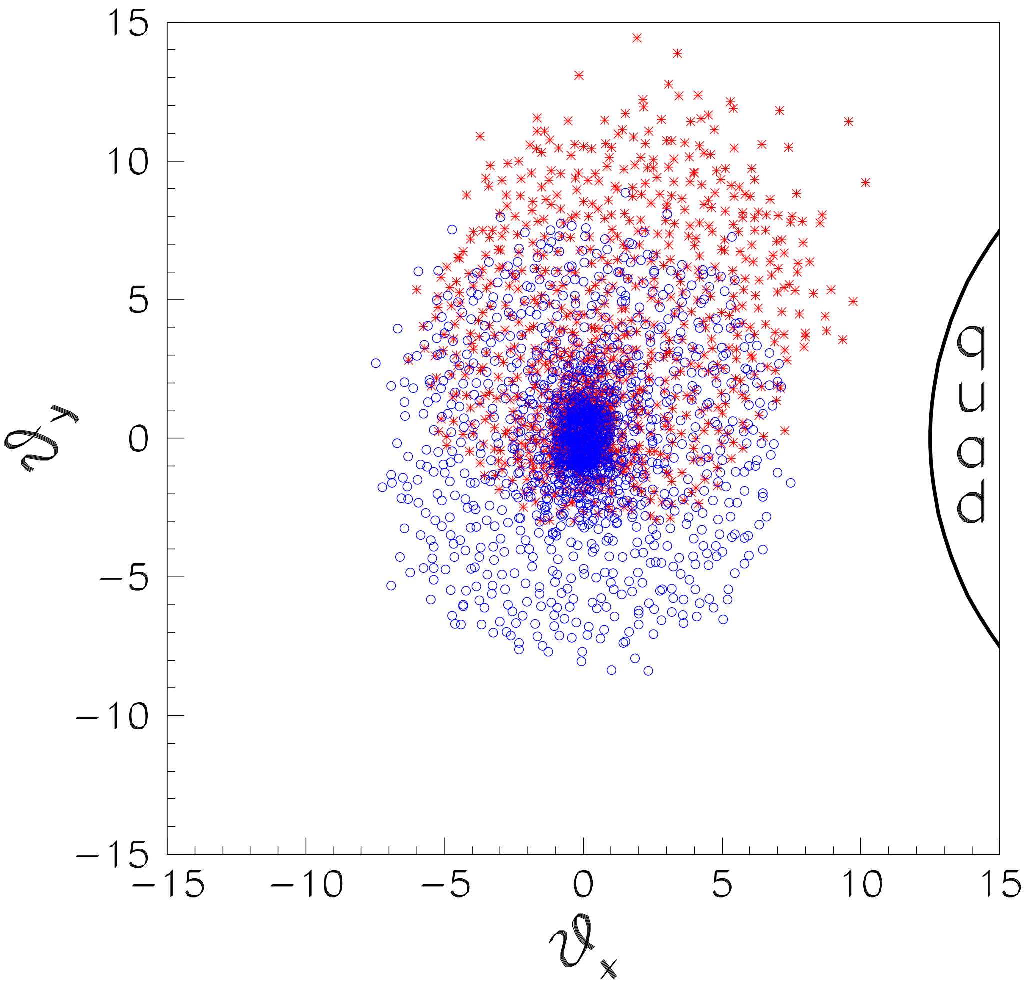

Removal of disrupted beams from the detector is one of most serious problem for the photon collider. After the interactions beams have very wide energy spread: $E \approx (0.02\text{-}1)E_0$ and large disruption angle (about 10 mrad at ILC). The problem is solved by using crab-crossing scheme where beams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

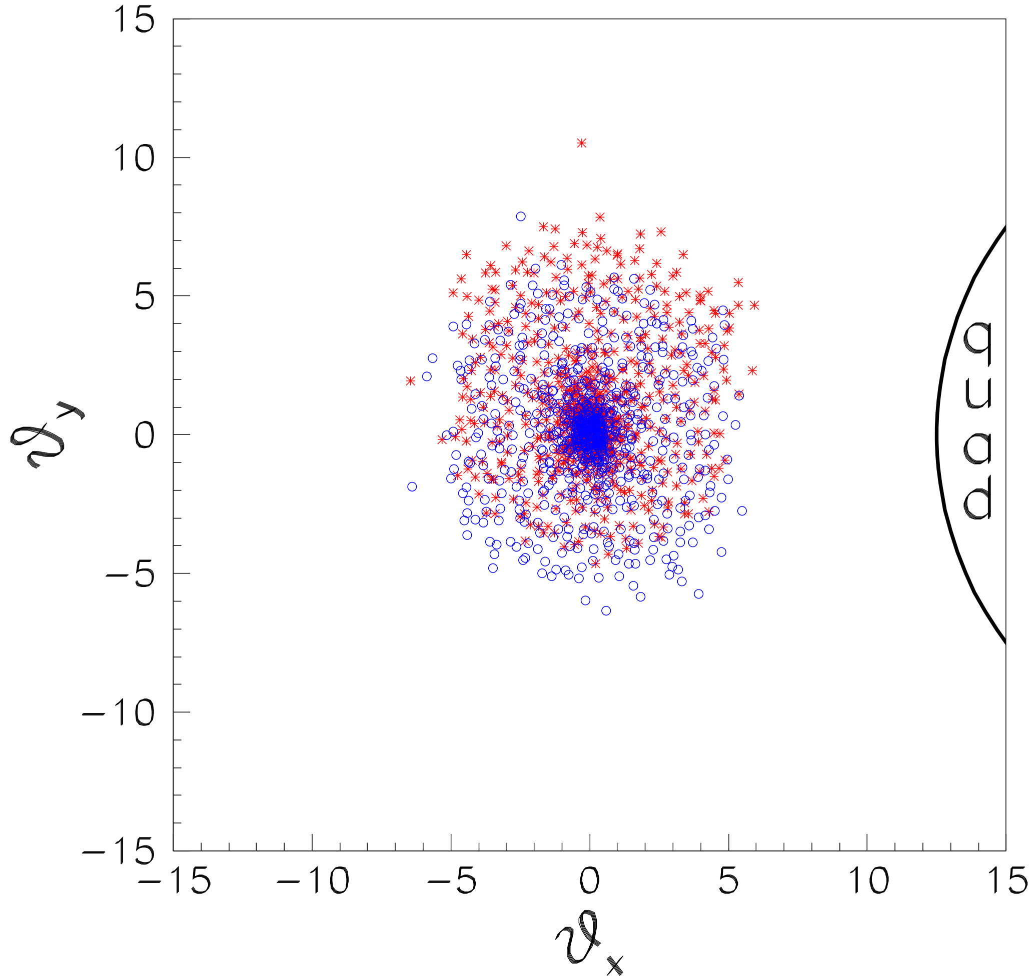



$2E_0$=500 GeV, λ=1 μm

$E_{min}$≈5 GeV

$\alpha_c$=25 mrad

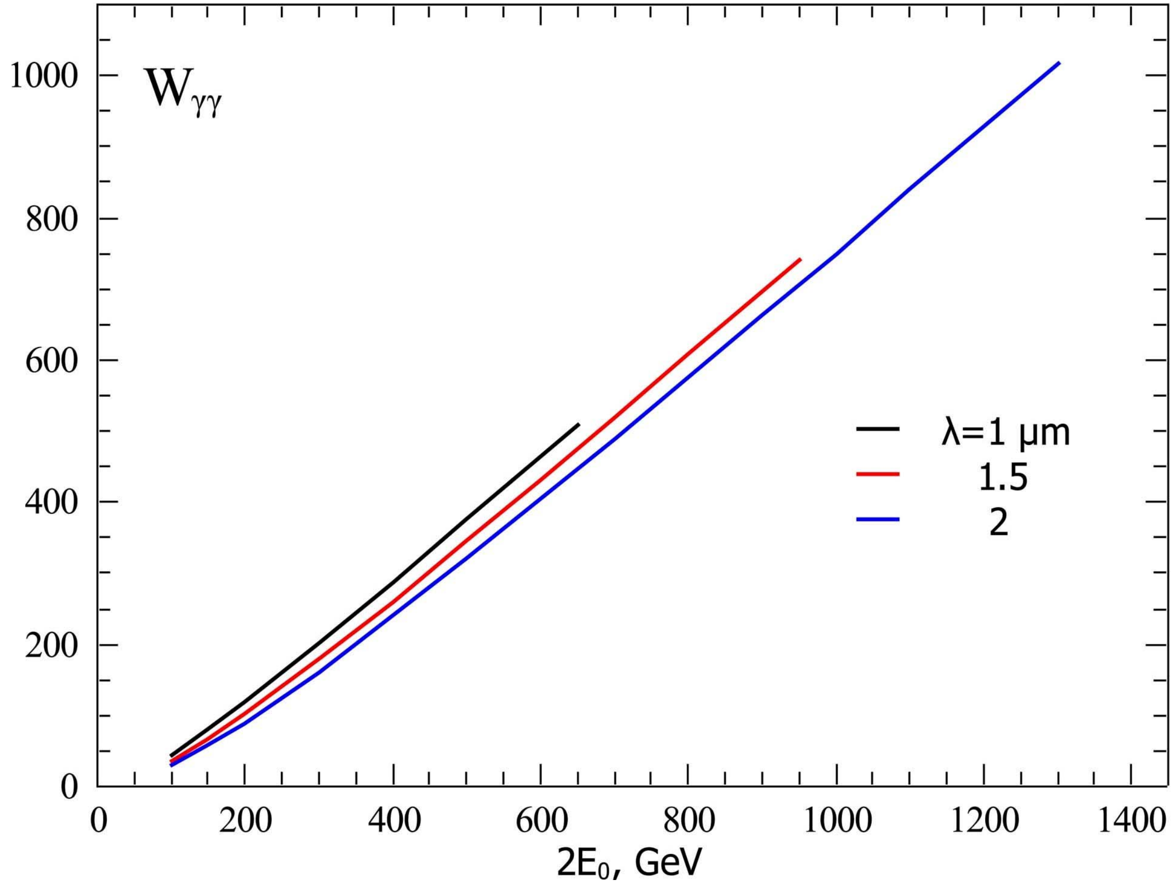
→




$2E_0$=1000 GeV, λ=2 μm

$\alpha_c$=25 mrad

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



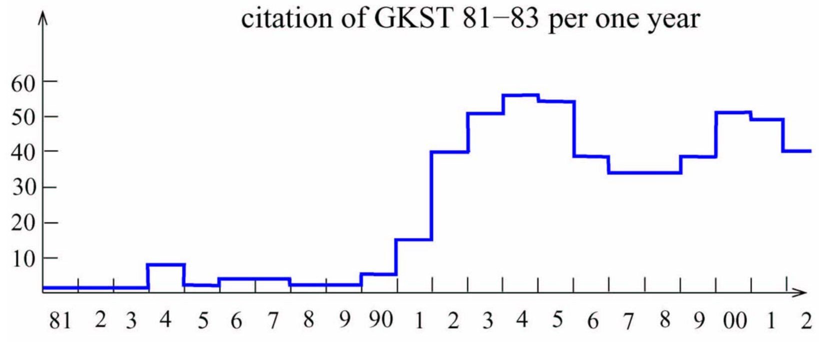

Here $W_{\gamma\gamma}$ corresponds to the peak of lum. spectra

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).

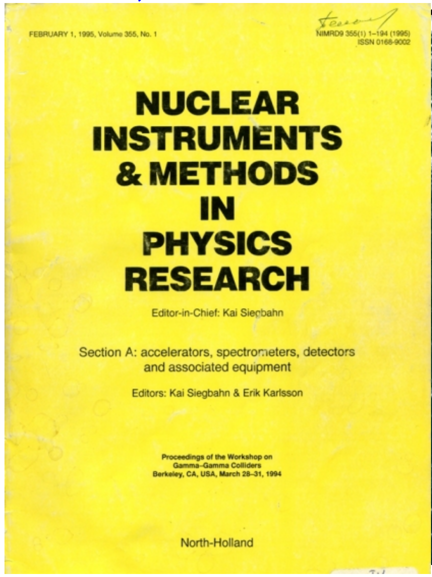
# Activity on photon colliders



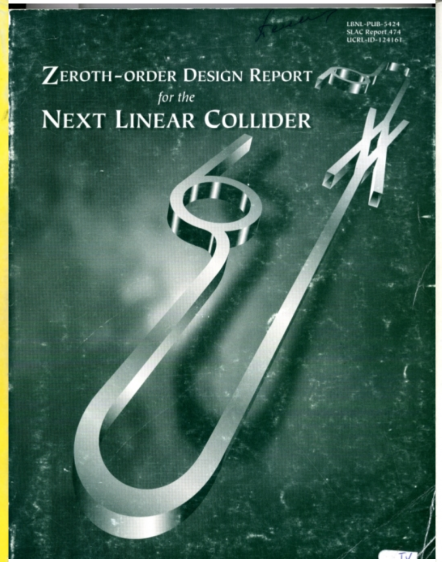

(total number of publications is larger by a factor of 2)

→ about 2 papers/week

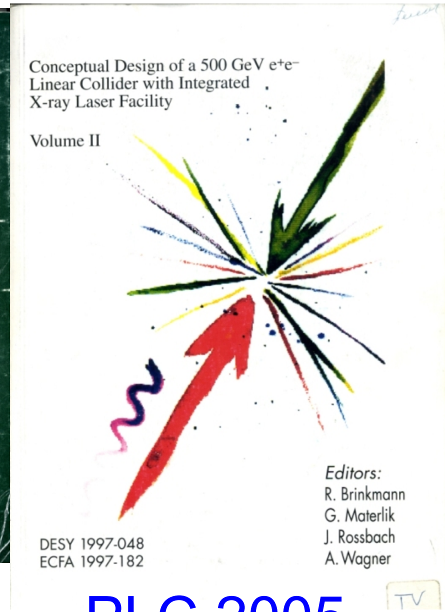
Gamma-gamma workshop LBL, 1994



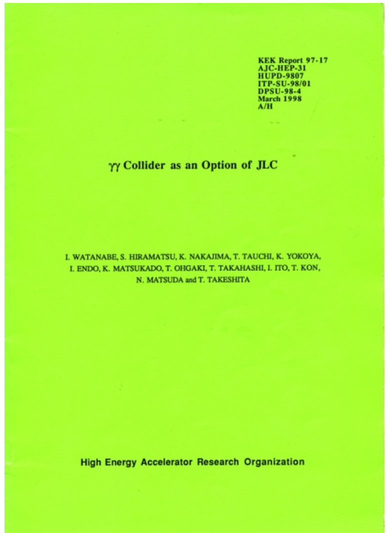

NLC



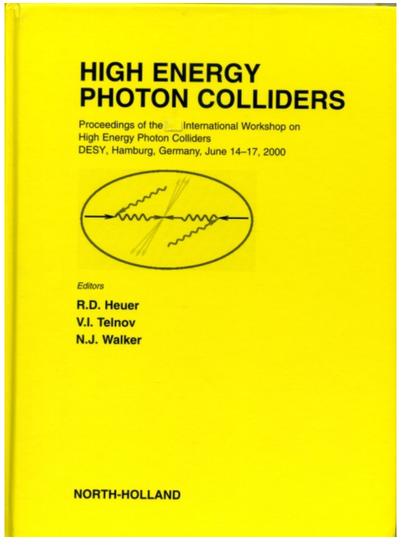

TESLA CDR



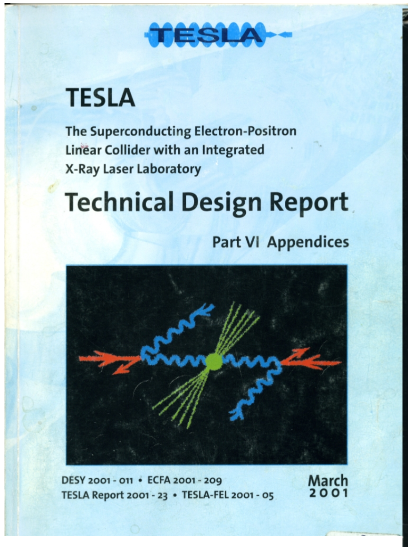

γγ at JLC



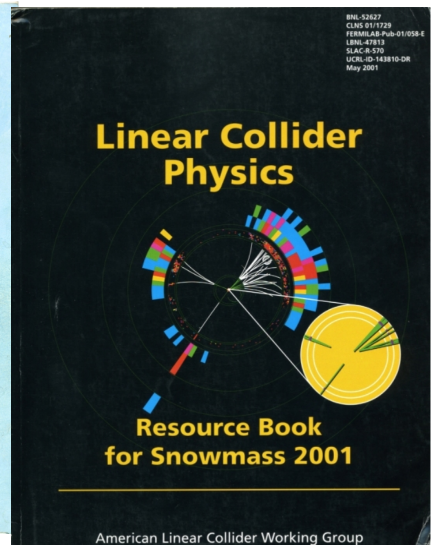

γγ workshop at DESY



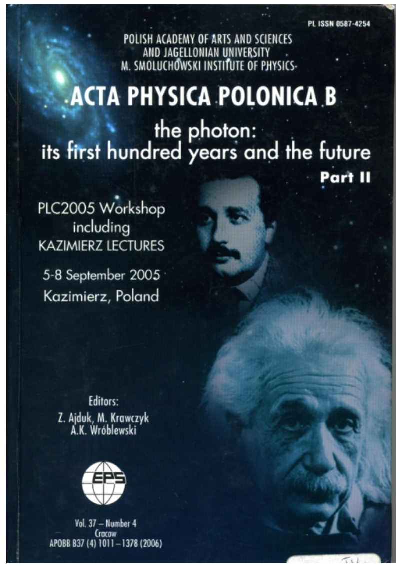

TESLA TDR




γγ NLC

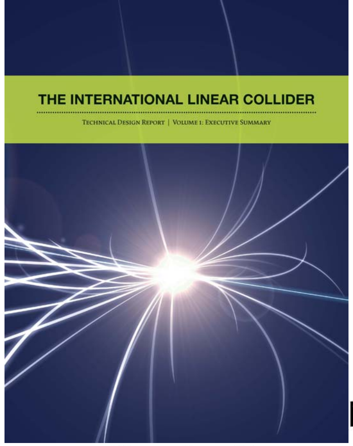



PLC 2005




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

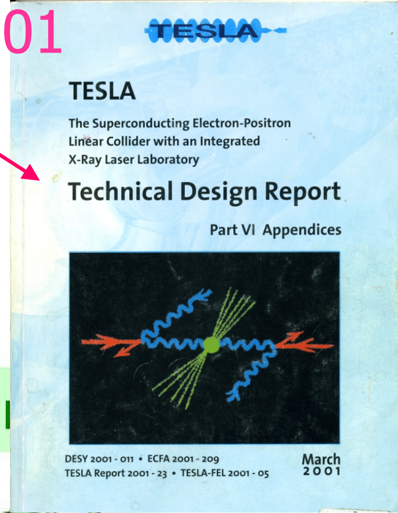
# Photon colliders at ILC and CLIC

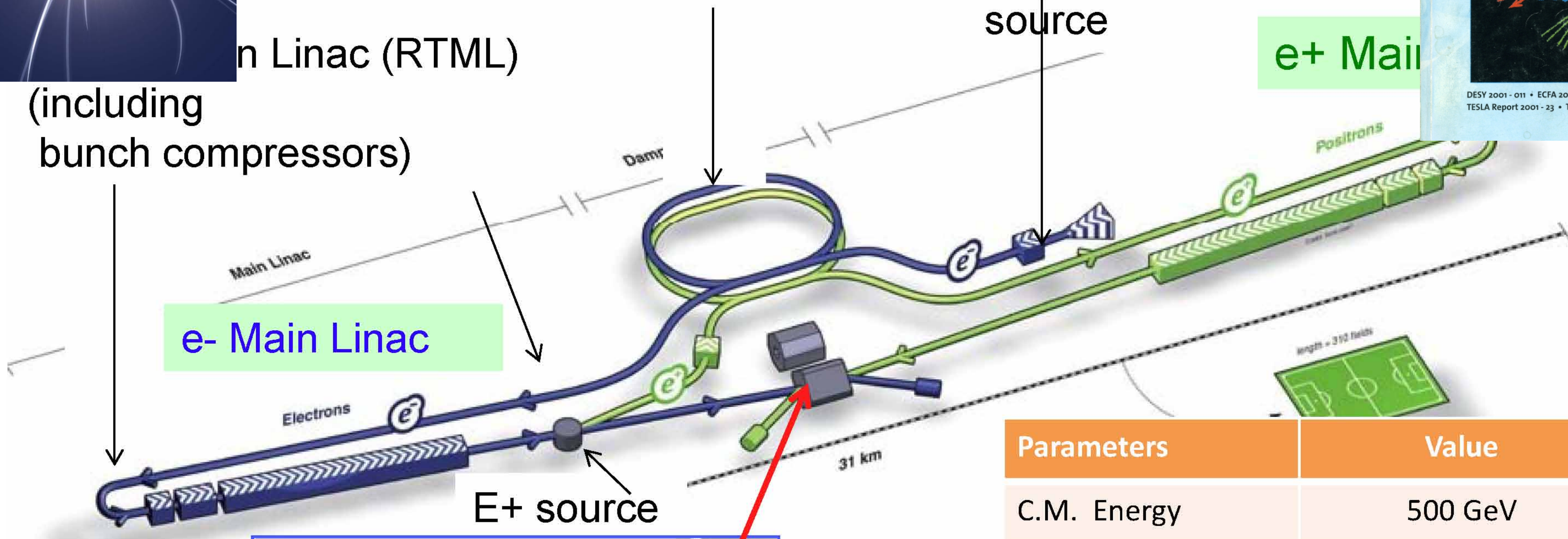


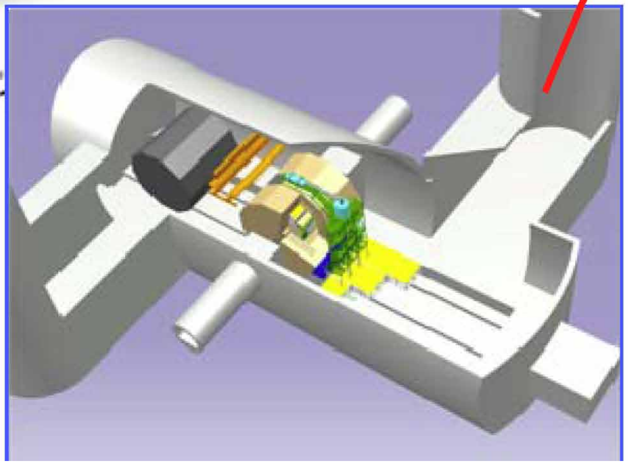

ILC TDR 6.2013

# ILC TDR Layout

PLC at TESLA, 2001



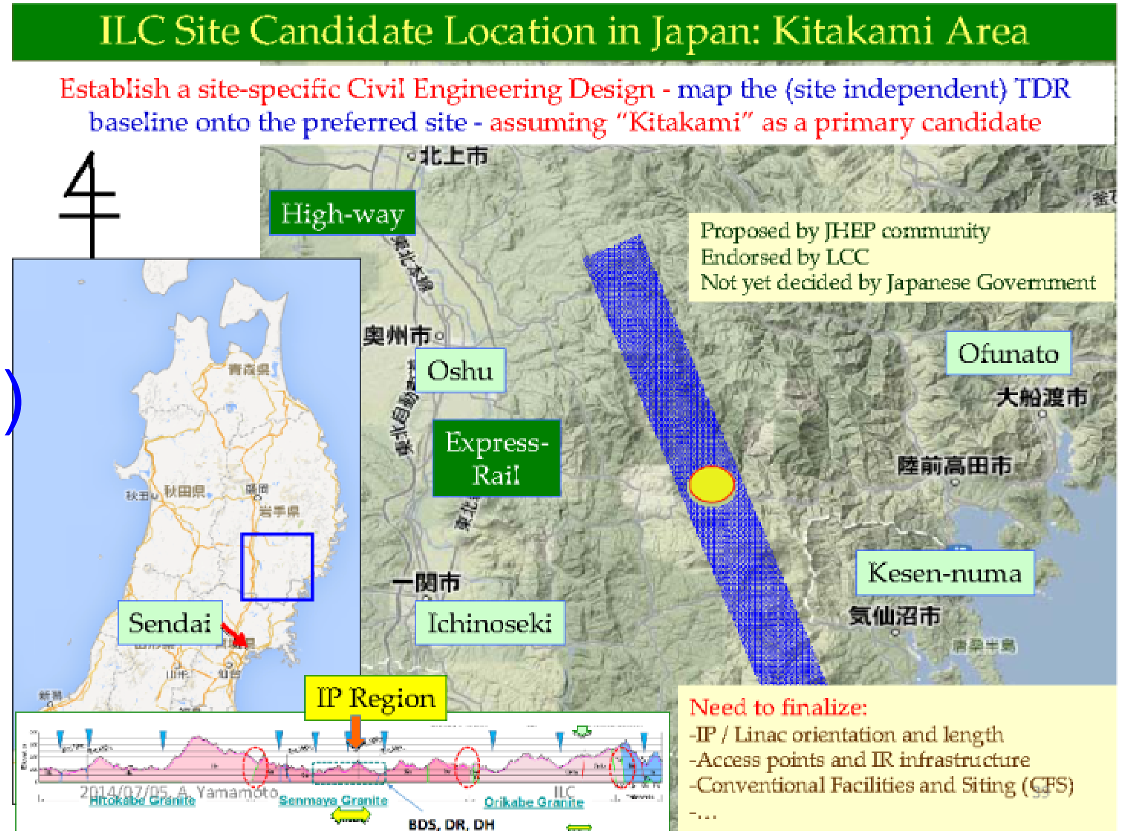
**L=31 km**
**2E=500 GeV**

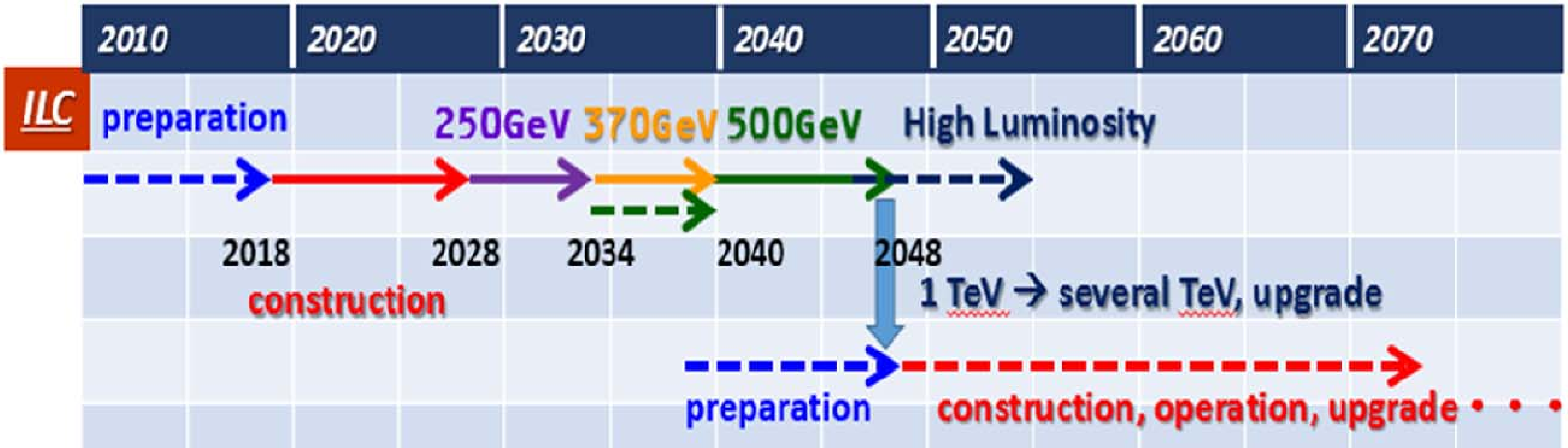
| Parameters | Value |
|---|---|
| C.M. Energy | 500 GeV |
| Peak luminosity | 1.8 x$10^{34}$ $cm^{-2}s^{-1}$ |
| Beam Rep. rate | 5 Hz |
| Pulse duration | 0.73 ms |
| Average current | 5.8 mA (in pulse) |
| E gradient in SCRF acc. cavity | 31.5 MV/m +/-20% $Q_0$ = 1E10 |

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

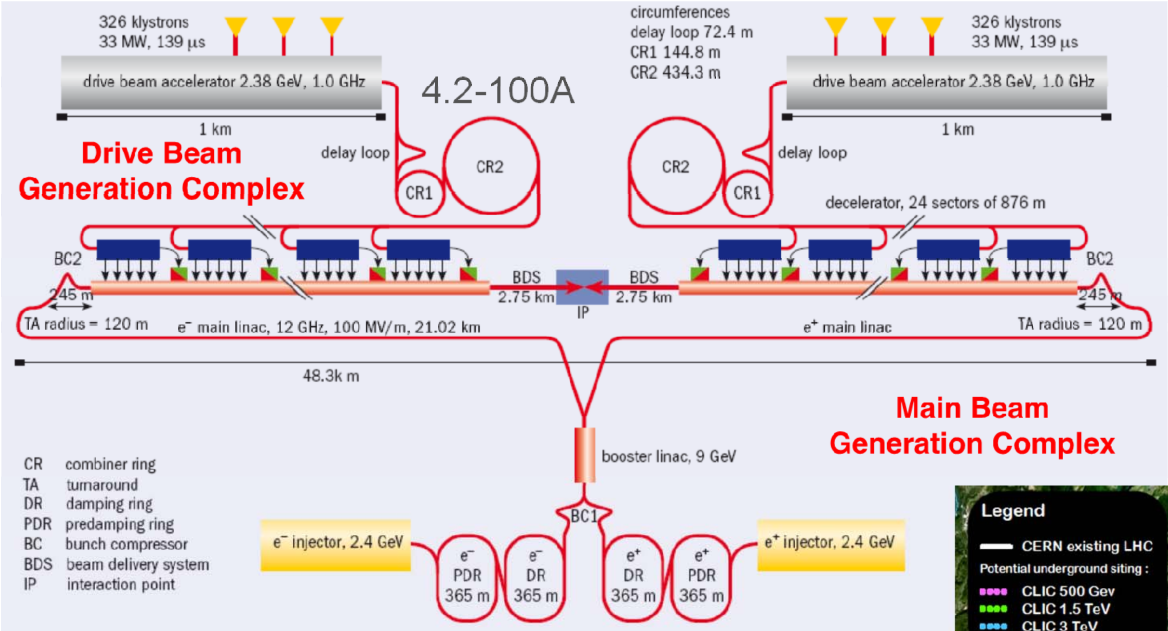
Japan is interested to host
-decision ~2018
-construction ~2019 (~10 years)
-physics ~2030

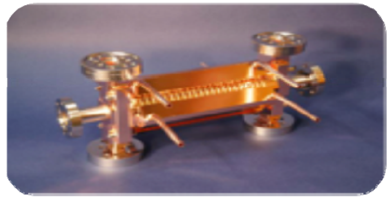
Unfortunately in this scenario the photon collider is possible here only in 40 years!



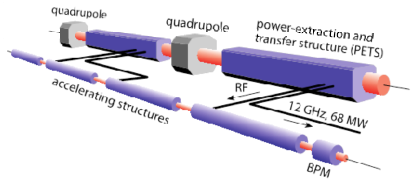



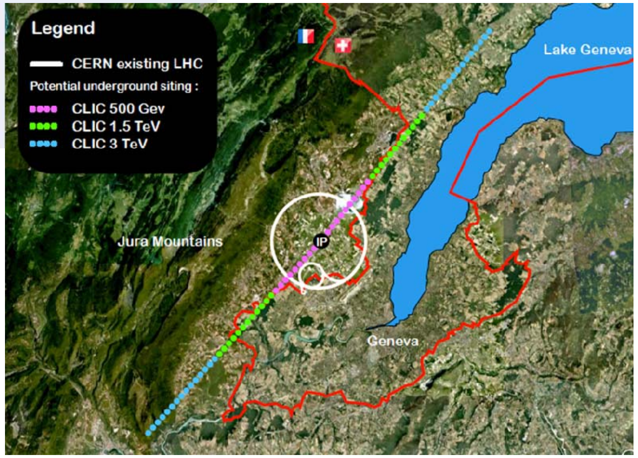
# Compact LInear Collider (CLIC)



$G_a \sim 100$ MV/m




0.5 TeV: 8,300 MCHF ($\mathcal{L} \sim 1.4\times10^{34}$)

- CLIC
  - e+e- 500 - 3000 GeV
  - x-band accelerator technology
  - 2-beam acceleration
  - $\mathcal{L} \sim 2\text{-}6\times10^{34}$

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

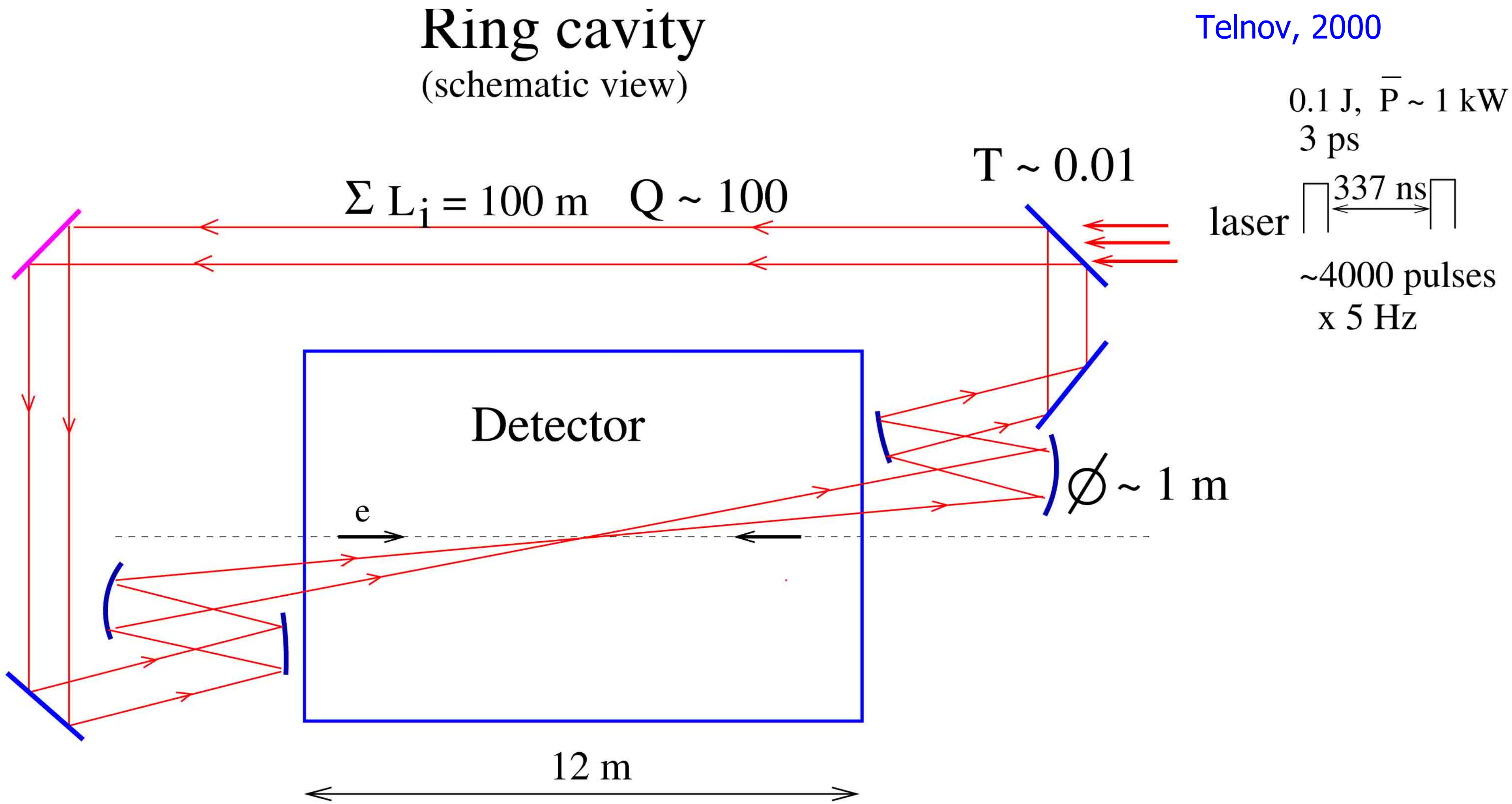
# Requirements for the ILC laser system

- 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

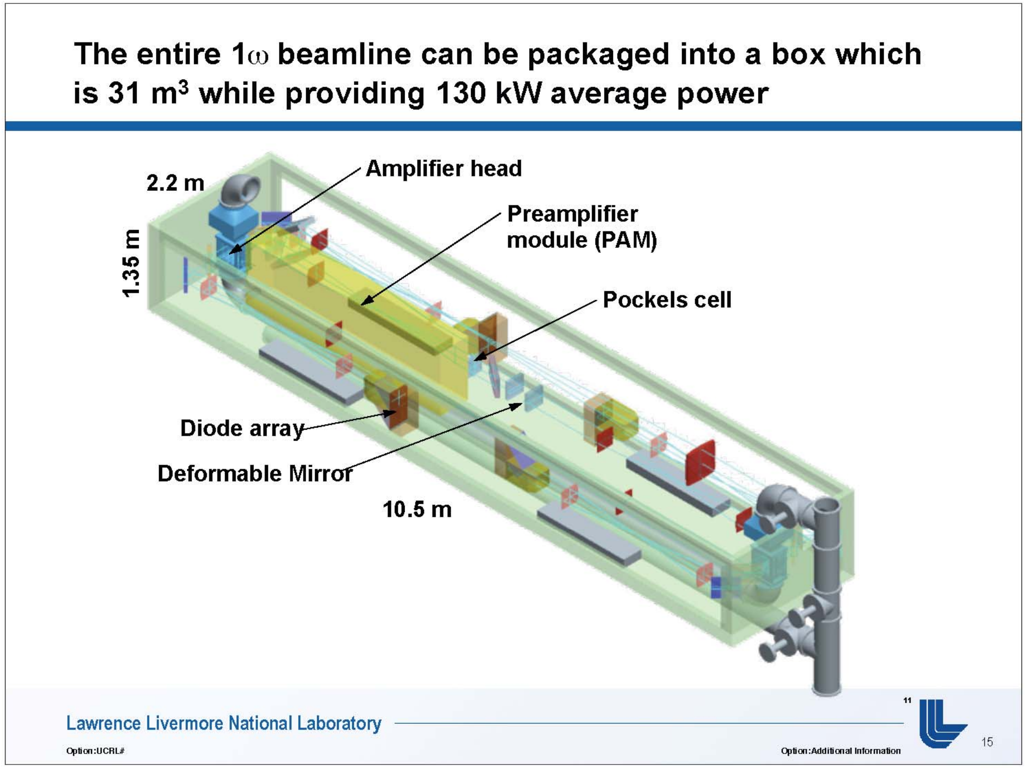



The cavity includes adaptive mirrors and diagnostics. Optimum angular divergence of the laser beam is ±30 mrad, A≈9 J (k=1), $\sigma_t \approx$ 1.3 ps, $\sigma_{x,L}$~7 μm

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!

This project is not approved yet

# 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, $\tau$~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

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

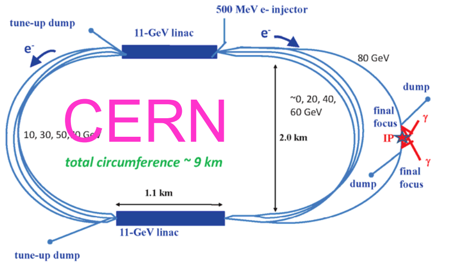
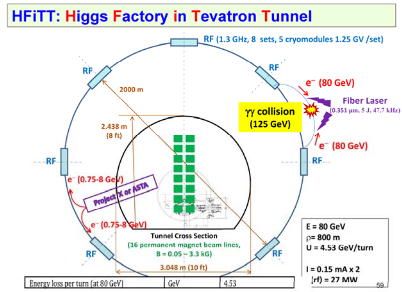



Figure 3: *Sketch of a layout for a γγ collider based on recirculating superconducting linacs – the SAPPHiRE concept.*

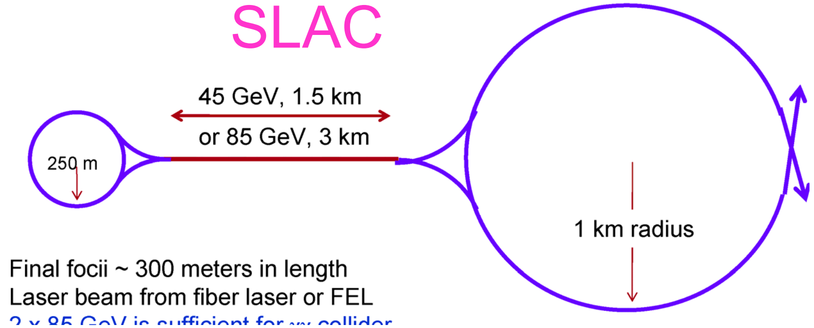




FNAL

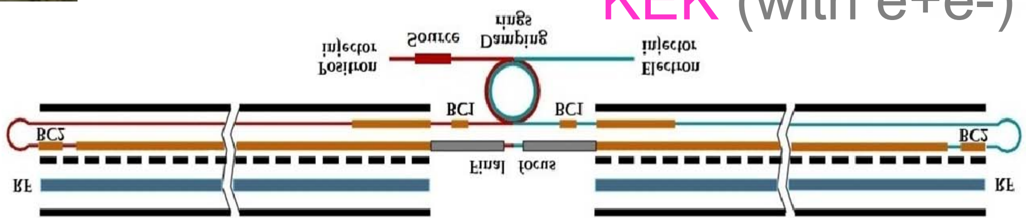
JLAB

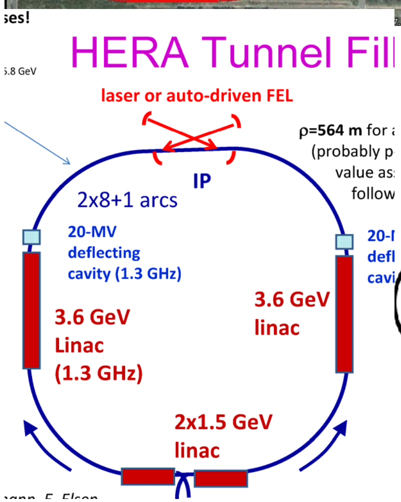
FNAL

SLAC

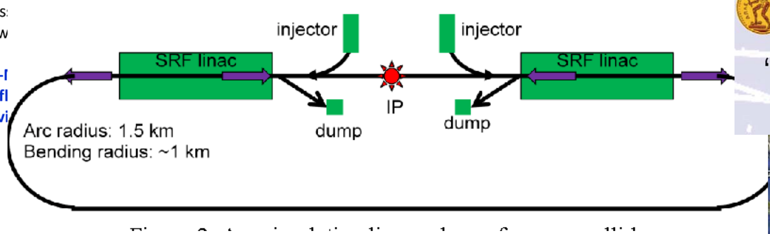



KEK (with e+e-)




JLAB





Turkey

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

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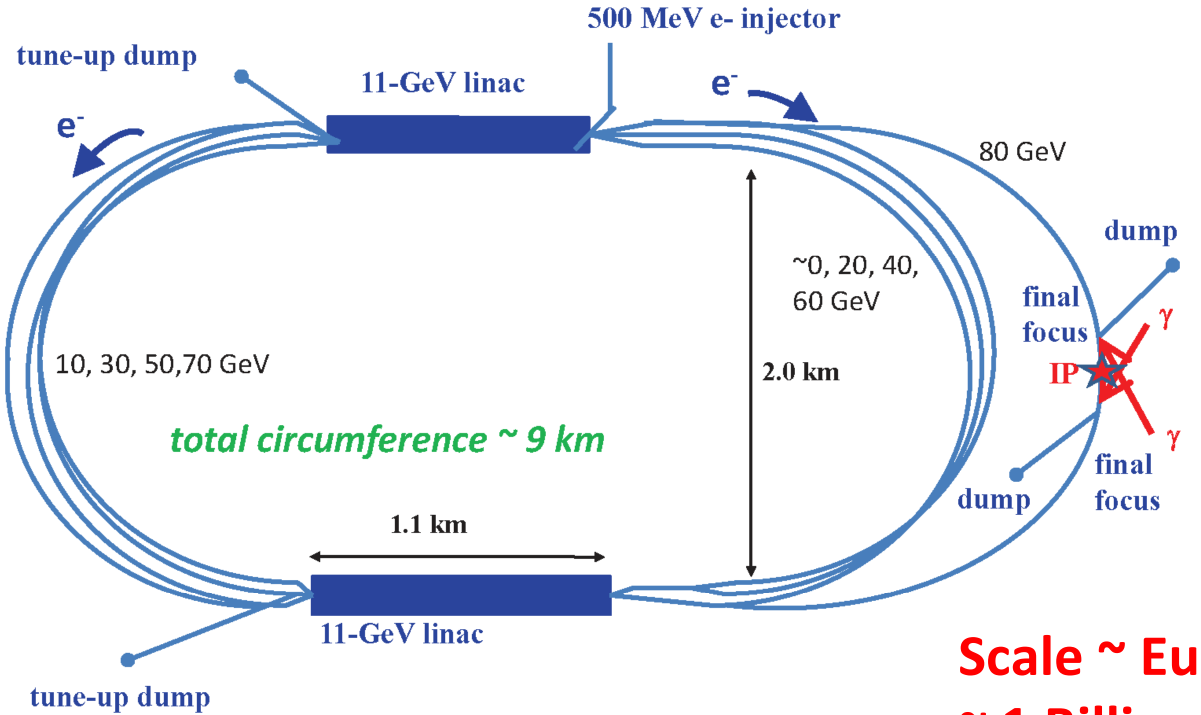


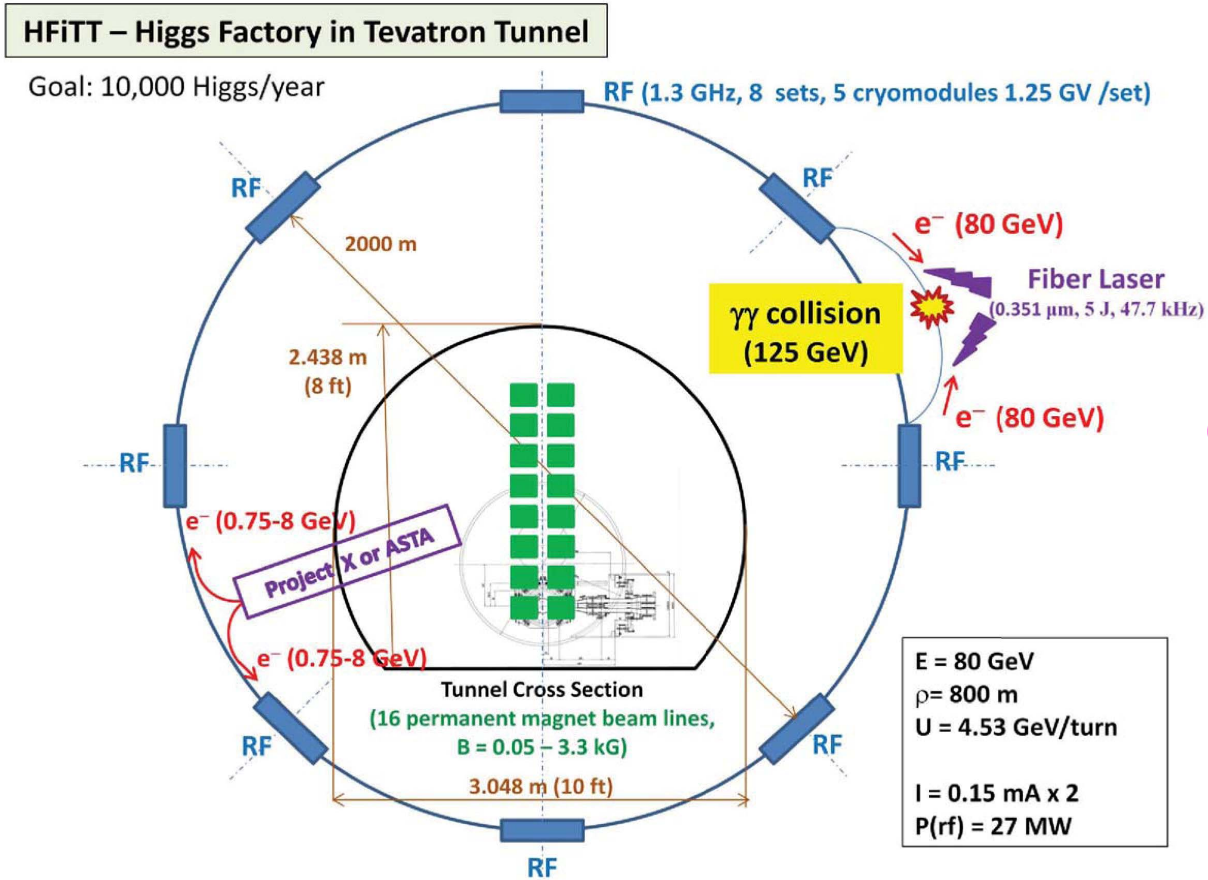

Scale ~ European XFEL
~ 1 Billion ???

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

# 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

SCHROEDER, ESAREY, GEDDES, BENEDETTI, AND LEEMANS Phys. Rev. ST Accel. Beams **13,** 101301 (2010)

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, $\gamma mc^2$ [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 [$\mu$m] | 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 [$e \to \gamma$] | 0.65 |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4 GeV beam in 9 cm plasma cell is produced (6% energy spread)

# Physics motivation for the photon collider at LC

(shortly, independent on a physics scenario)

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

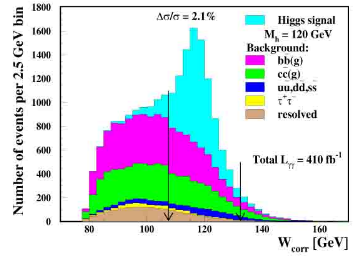
- the energy is smaller only by 10-20%
- the number of interesting events is similar or even higher
- access to higher particle masses (H,A in $\gamma\gamma$, charged and light neutral SUSY in $\gamma e$)
- higher precision for some phenomena ($\Gamma_{\gamma\gamma}$, CP-proper.)

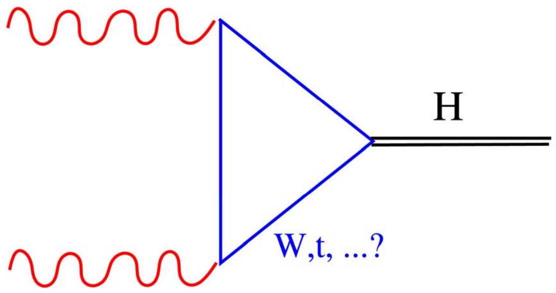
  $\Gamma(H \to \gamma\gamma)$ width can be measured with statistics ≈ 60 times higher than in e+e- collisions.
- different types of reactions (different dependence on theoretical parameters)

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

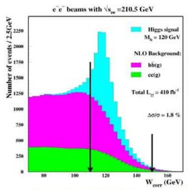
Unfortunately, the physics in LC region is not so rich as expected, by now LHC found only light Higgs boson.

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

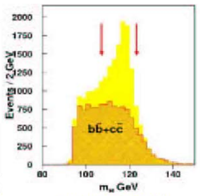


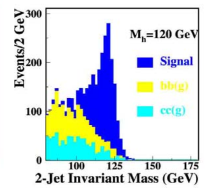

Very sensitive to high mass particles in the loop



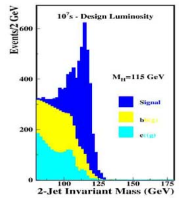
Niezurawski(TESLA)




Rosca(TESLA)




Asner(NLC)




Asner(Cliche)

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

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

For realistic ILC conditions $\sigma(\gamma\gamma\to H)\approx$75 fb, while $\sigma(e^+e^-\to HZ)\approx$290 fb

in e+e- N(H→γγ)∞ L σ($e^+e^-$→HZ)*Br(H→ γγ), where Br(H→ γγ)=0.0024

in γγ N(H→γγ)∞ L σ(γγ→H)*Br(H→ bb), where Br(H→ bb)=0.57

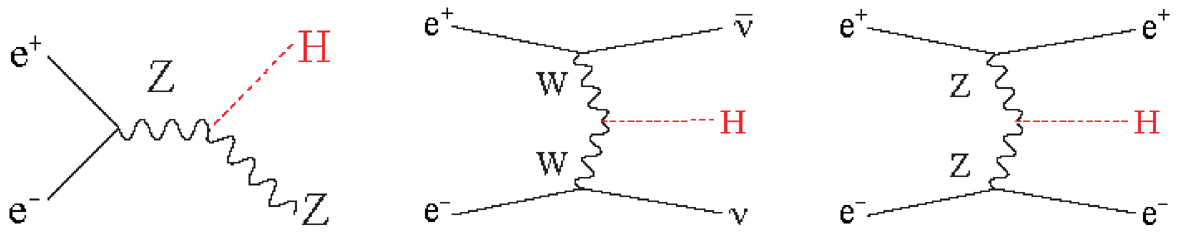
Conclusion: in γγ collisions the Γ(H→γγ) width can be measured with statistics (75*0.57)/(290*0.0024)=60 times higher than in e+e- collisions.

That is one of most important argument for the photon collider.

# Remark on Photon collider Higgs factories

Photon collider can measure
$\Gamma(H\to\gamma\gamma)$*$Br(H\to bb, ZZ, WW)$, $\Gamma^2(H\to\gamma\gamma)/\Gamma_{tot}$, Higgs 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 1 years of operation. Other Higgs decay channels will be unobservable due to large QED background.

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



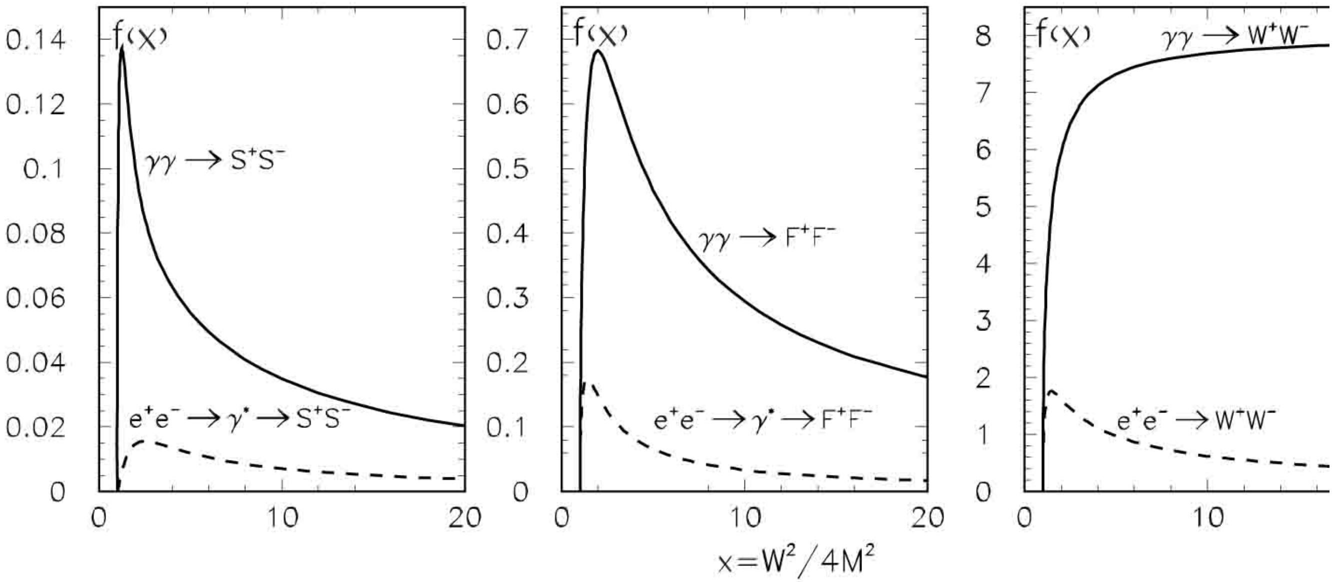

Therefore PLC is nicely motivated in only in combination with e+e-: parallel work or second stage.

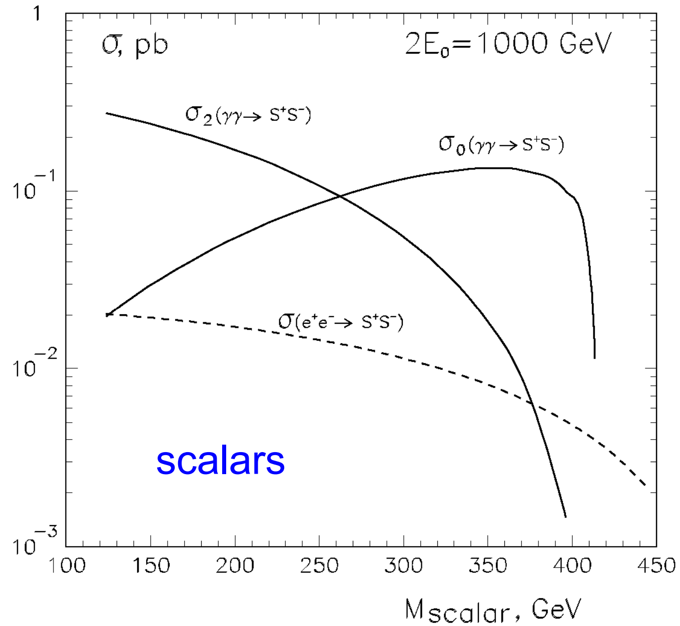
# Some examples of Physics (in addition to H(125))

## 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)

Not seen at LHC

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

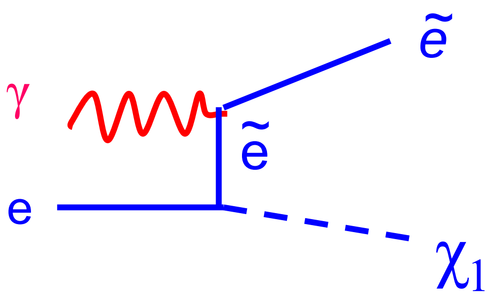
For some SUSY parameters H,A can be seen only in $\gamma\gamma$
(but not in e+e- and LHC)

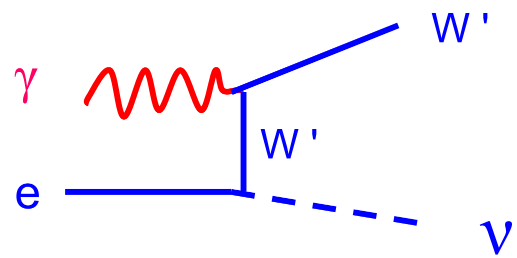
Not seen at LHC

# Supersymmetry in $\gamma$e

At a $\gamma$e 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):

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




Not seen at LHC

V. Telnov

A new proposal (4.2017)

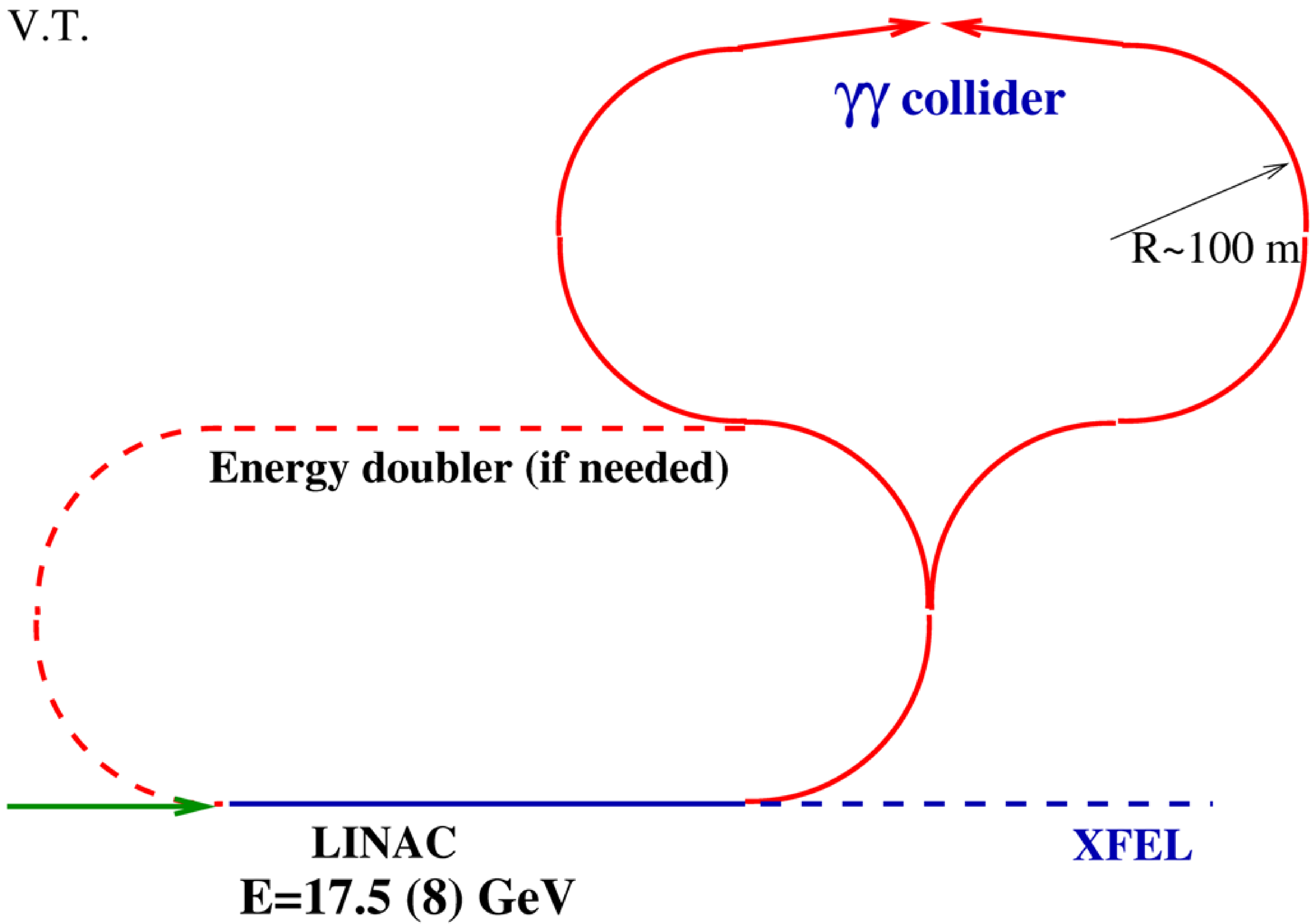
# The Photon collider based on European XFEL with $E_0 \approx 17.5$ GeV

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

or a plasma accelerator

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

# Scheme of the collider

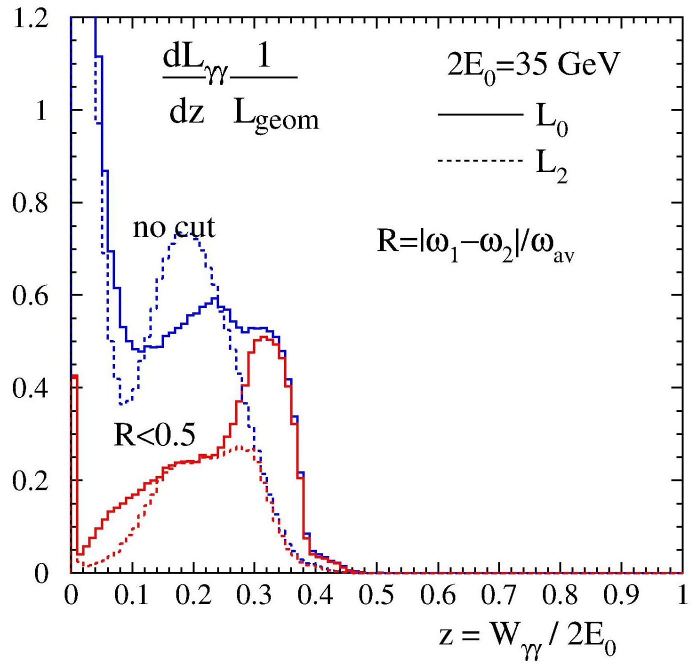



Linac not in scale

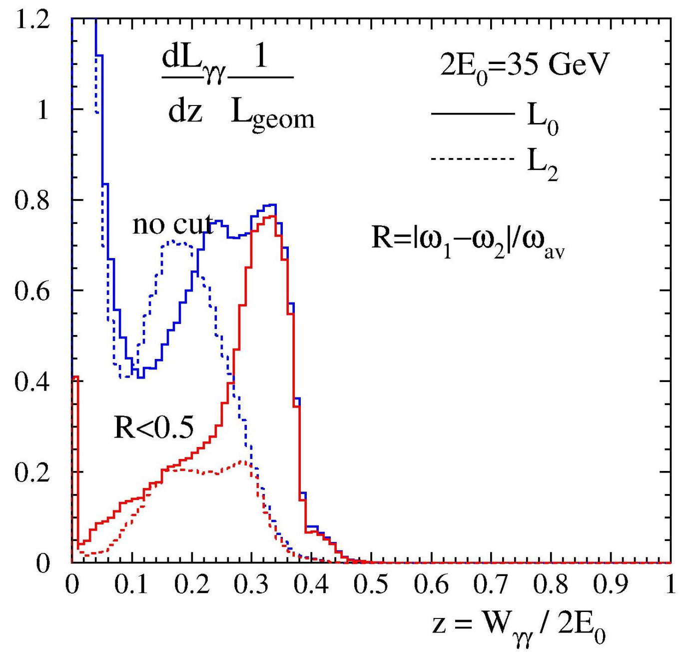
European Superconducting XFEL has started operation in 2017. Its e-beam parameters: $E_0$=17.5 GeV, N=0.62·$10^{10}$ (1 nQ), $\sigma_z$=25 μm, $\varepsilon_n$=1.4 mm mrad, f≈30 kHz

Using arcs with R~100-200 m we can get the photon collider with f=15 kHz. Other parameters for γγ collider: $\beta^*$=70 μm, $\sigma_z$=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

Wγγ 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 = +, $J^P$= $0^+$, $0^-$, $2^+$, $2^-$, $3^+$, $4^+$, $4^-$, $5^+$ … $(\text{even})^{\pm}$, $(\text{odd} \neq 1)^+$

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

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 $\gamma\gamma$ collider $\dfrac{dL_{\gamma\gamma} 2E_0}{dW_{\gamma\gamma} L_{ee}} \simeq 0.5$, 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 $N(\eta_b) \approx 1.5 \cdot 10^5 - 2 \cdot 10^6$ and can 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'').

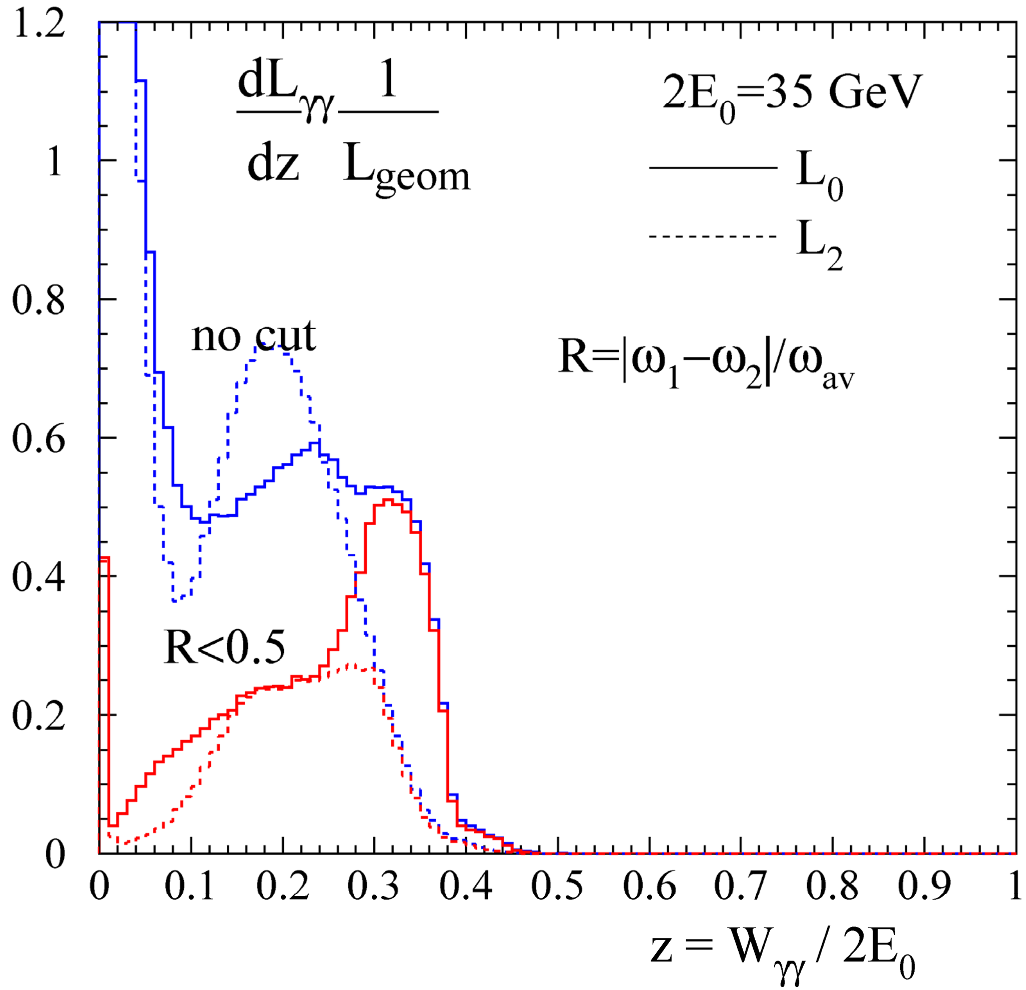
Just for information. $\eta_b$ was detected in radiative decays of ϒ(nS). Babar has detected ~ 30000 $\eta_b$, this was not sufficient to observe its decay to γγ, because Br~$7 \cdot 10^{-5}$.

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

V. Telnov

| | |
|---|---|
| $E_0$, GeV | 17.5 (23) |
| $N/10^{10}$ | 0.62 |
| f, kHz | 15 |
| $\sigma_z$, μm | 70 |
| $\varepsilon_{nx}/\varepsilon_{ny}$, mm mrad | 0.1/0.1 |
| $\beta_x/\beta_y$, μm | 70/70 |
| $\sigma_x/\sigma_y$, nm | 14/14 |
| laser λ, μm | 0.5 (1) |
| laser flash energy, J | 3 ($\xi^2$=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 |
| Wγγ(peak), GeV | 12 |

Unpolarized electrons, $P_c$=-1




In Table a low emittance plasma gun is assumed. With the XFEL gun the luminosity is smaller ~15 times.

In order to get $W_{\gamma\gamma} \leq 12$ GeV one needs

$E_0 = 17.5$ GeV and $\lambda = 0.5$ μm

or $E_0 = 23$ GeV and $\lambda = 1$ μm

## Polarization

Gamma beams have high degree of circular or linearly polarization at maximum energies that allows to measure easily S and P-parity of resonances (C=+)

## Absence of e+e induced backgrounds

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 γγ-collider there are no such backgrounds

# $c\bar{c}$

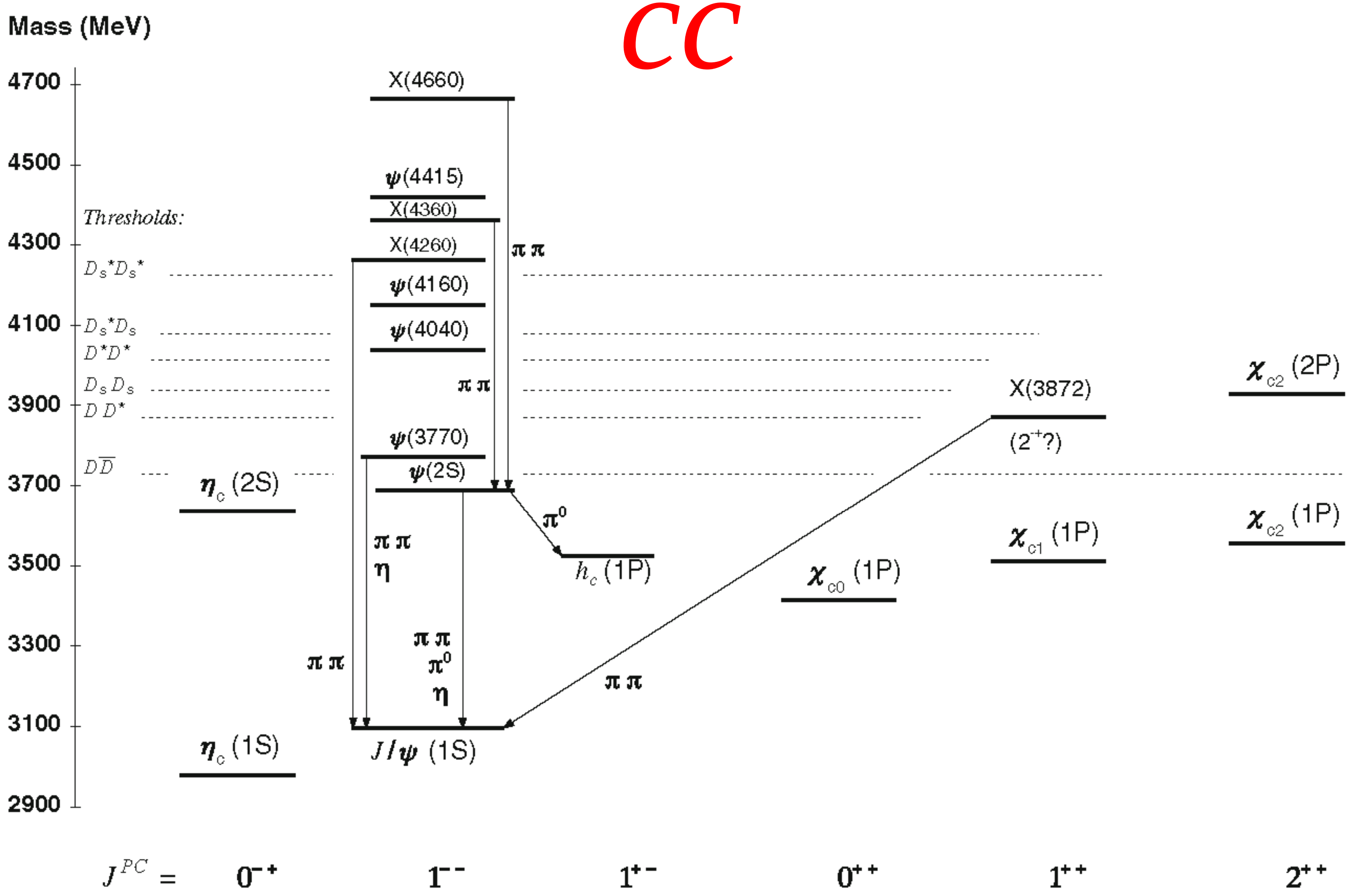



**Fig. 2.1** The experimentally observed charmonium states. The states labelled $X$, the nature of which is unknown, are not thought to be conventional charmonium states. Figure from Ref. [1]

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

# $b\bar{b}$

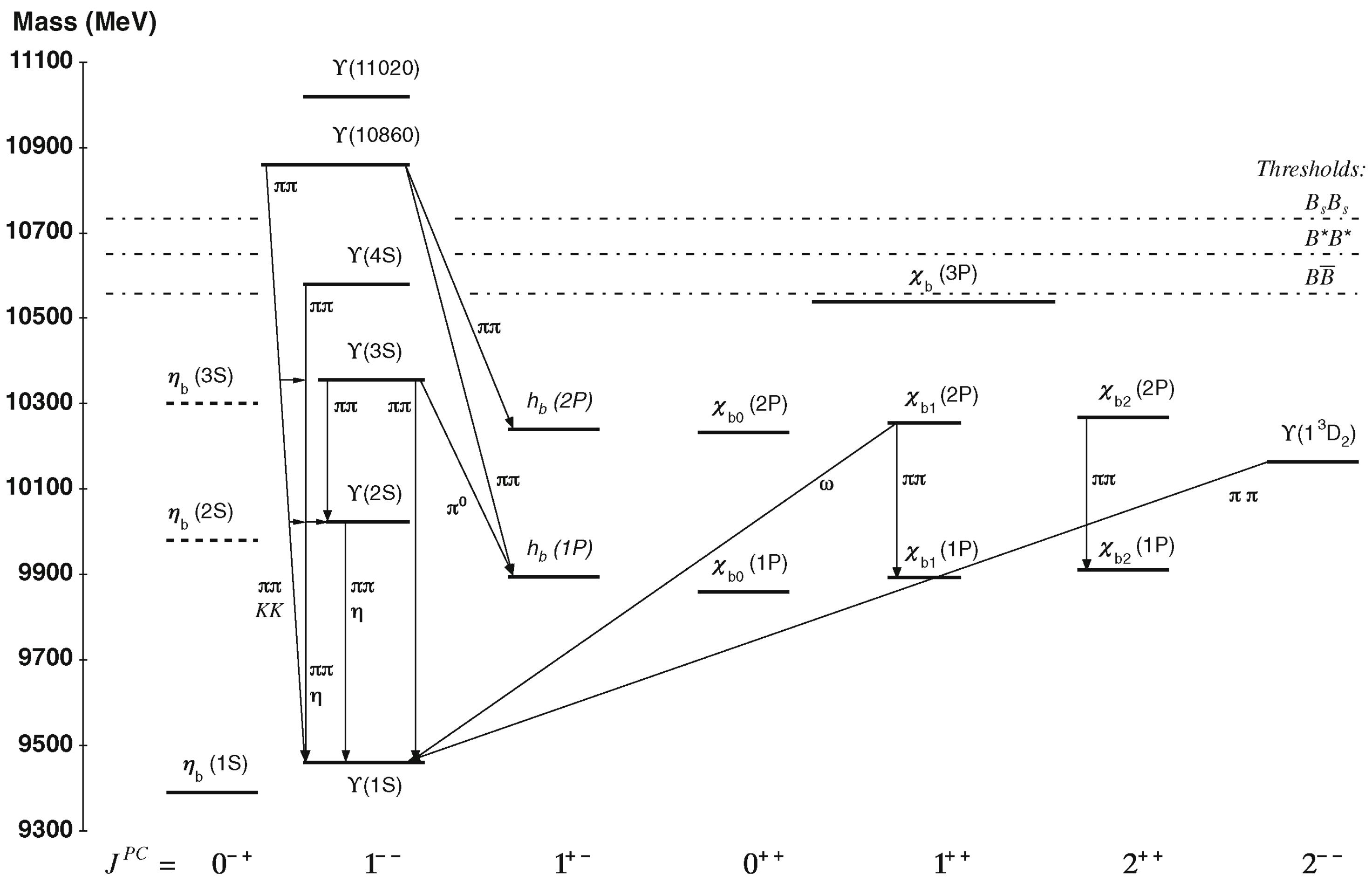



**Fig. 2.2** The experimentally observed and theoretically expected bottomonium states. *Dashed lines* denote unobserved or unconfirmed states (an unconfirmed experimental candidate for the $\eta_b(2S)$ state has been observed by the Belle experiment [6]). Figure from Ref. [1]

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 thresholds are not observed yet because they are detected in radiative decays of $\Psi$ and $\Upsilon$, which become broad above the threshold (and radiative branching becomes very small).

In $\gamma\gamma$-colliisons these resonances will be produced directly. Their increased total width does not influence the production rate in $\gamma\gamma$-collisions which is proportional to $\Gamma_{\gamma\gamma}$.

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

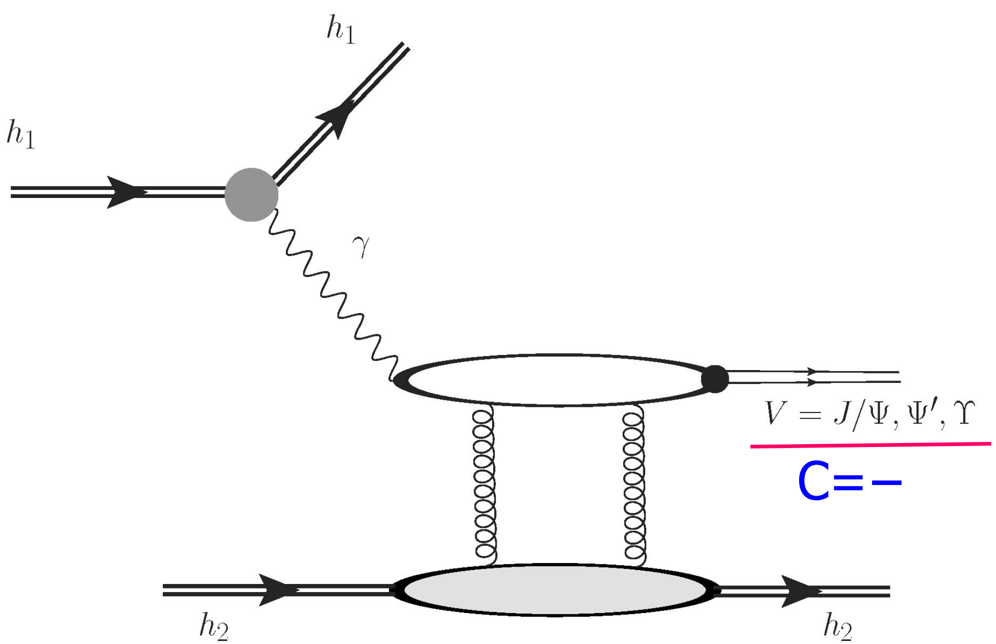
$$\frac{(dL/dW)_{\gamma\gamma-factory}}{(dL/dW)_{LHC}} \sim 50\frac{L_{ee}}{L_{pp}}$$

Important:
in pp (or heavy ion-ion) collisions there is a huge background from diffractive processes (pomeron-pomeron, photon-pomeron) interactions that makes the study of γγ processes very problematic.

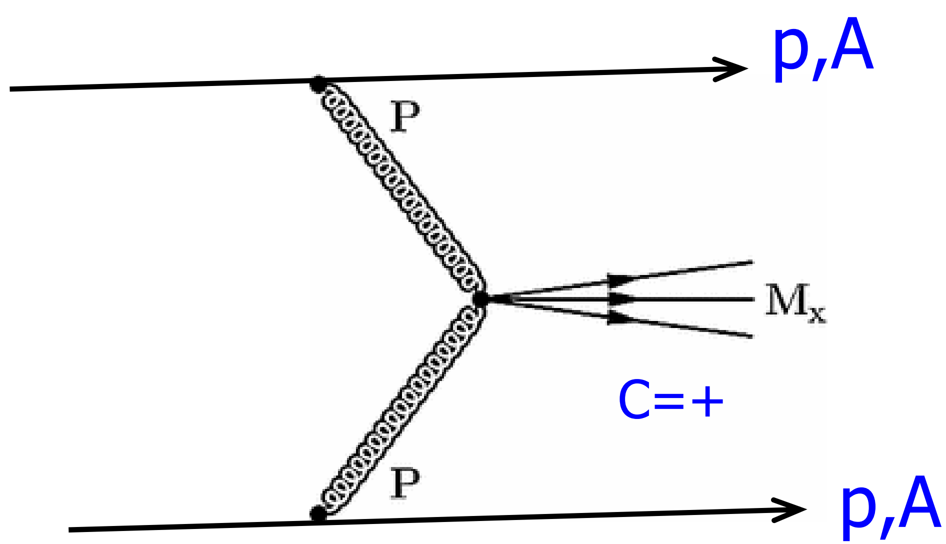
For example, at LHC in photon-pomeron(P) collision C=– resonances are produced which are forbidden in γγ-collisions

P – Pomeron - multigluon state

γP




PP




final states are quite similar to those in γγ-collisions, only wider transverse momentum distribution

So, LHC can't compete in study of γγ-processes with a clean γγ-collider

# Conclusion

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

- It has sense to construct a smaller photon collider on the energy $W_{\gamma\gamma} \leq 12$ GeV (b,c regions). $\gamma\gamma$ physics here is very rich.

- Such $\gamma\gamma$ collider will be a nice place for application of modern outstanding accelerator, laser and plasma technologies (linacs (SC, plasma-based), low-emittance electron sources (incl. plasma), powerful laser systems, optical cavities). It does not need positrons and damping rings. The same electron linacs can be used simultaneously for XFELs.