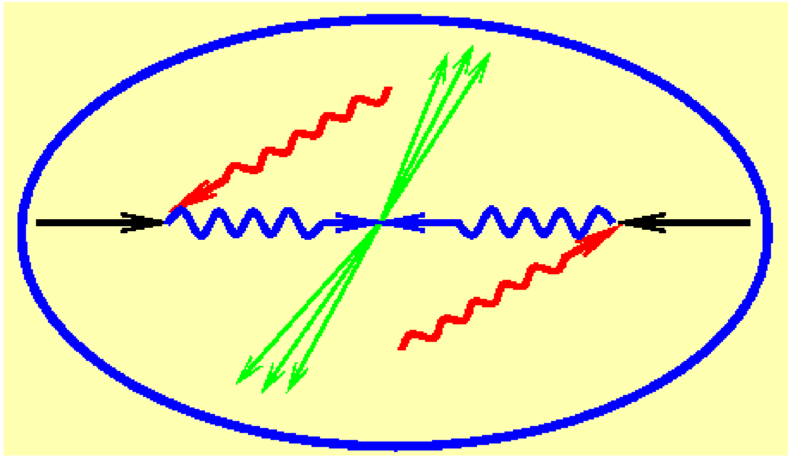


Photon Colliders

Valery Telnov

Budker INP, Novosibirsk

Photon2011,

SPA,Belgium, May 25,2011

Contents

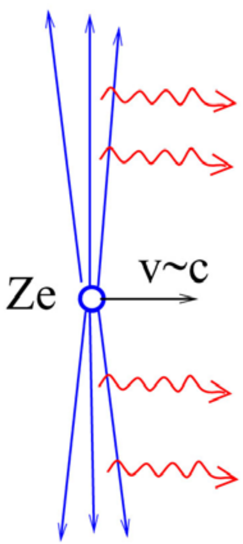
- PLC: 30 years, basic features
- $e \to \gamma$ conversion, lasers, optics

  (new: laser scheme for CLIC)
- Luminosity

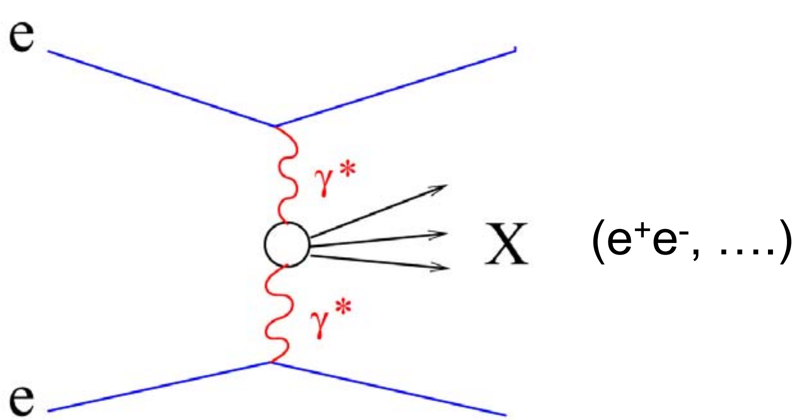
  (new: PLC without damping rings)
- Physics at the PLC
- Conclusion

Colliding $\gamma^*\gamma^*$ photons

The idea to study some physics in photon-photon collisions is about 80 years old. The cross section for two-photon production of a charge pair above a threshold is large, 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 process



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

1970 $e^+e^- \to e^+e^-e^+e^-$ Novosibirsk
1972 $e^+e^- \to e^+e^-\mu^+\mu^-$ Frascati
1979 $e^+e^- \to e^+e^- \to \eta'$ SLAC
+many processes after 1979 from all detectors

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

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

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

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

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

Collision of real photons- Photon collider

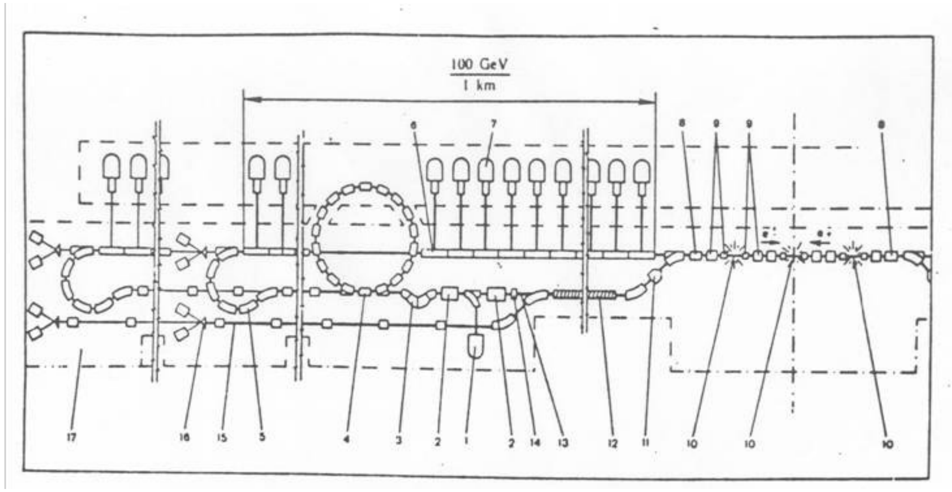
The idea of the Photon collider (1981) is based on the fact that at linear colliders electron beams are used only once which makes possible to convert electron beam to high energy photons just before the interaction point (it is not possible at storage ring).

The conversion can be done placing some target just before the interaction point, the best way is the Compton scattering of the laser light off the high energy electrons in the linear collider (laser target). Thus one can get the energy and luminosity in $\gamma\gamma$ collisions close to those in e+e- collisions:

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

First projects of linear e^+e^- colliders

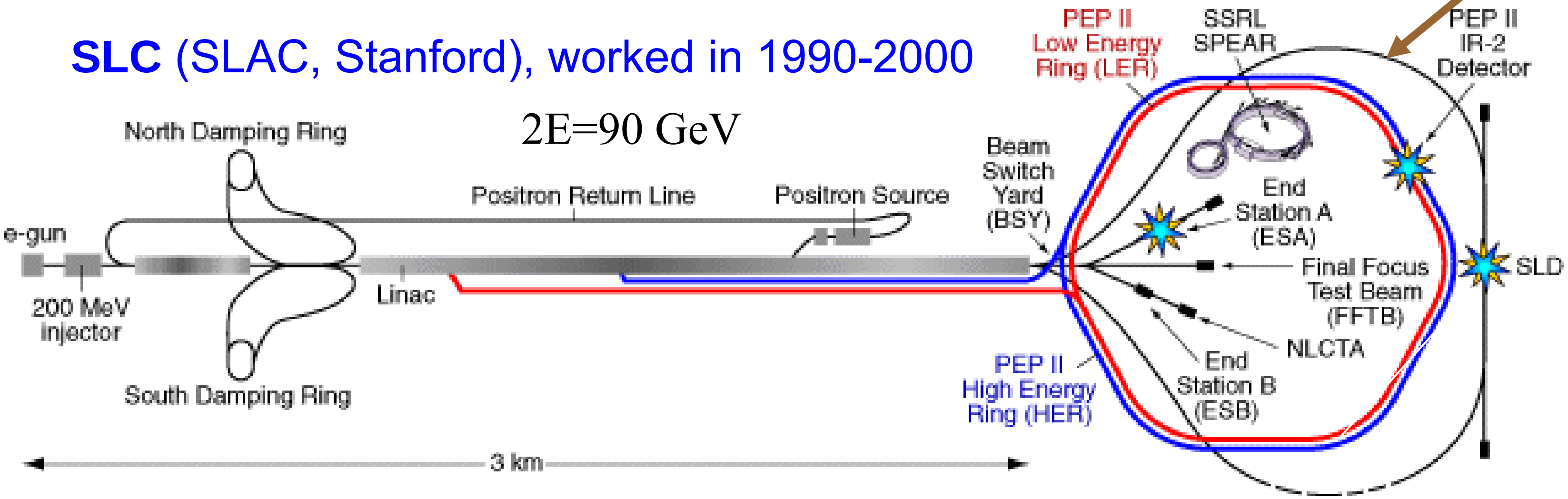
VLEPP (Novosibirsk)! 2E~0.5 TeV
(1978-1997, proposal published in 1986)



SLC (SLAC, Stanford), worked in 1990-2000

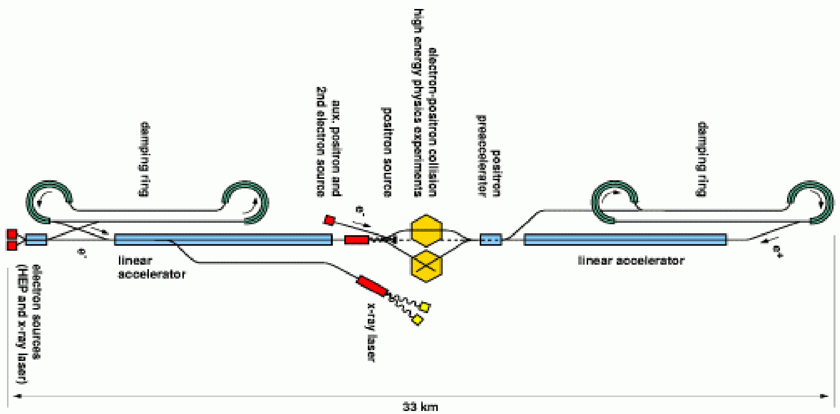
2E=90 GeV

SLC

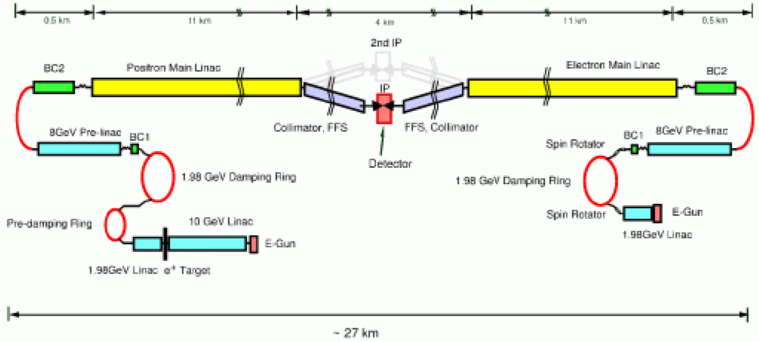


Projects of linear e^+e^- colliders (~1988-2004)

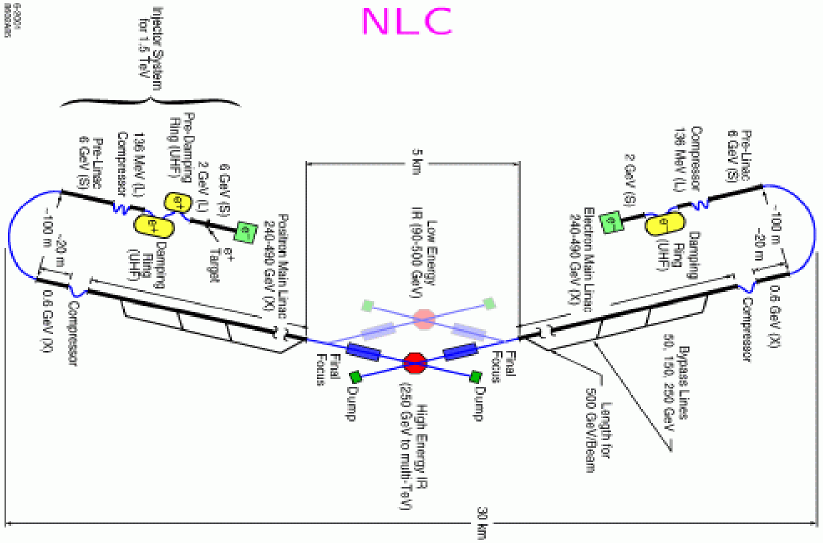
TESLA



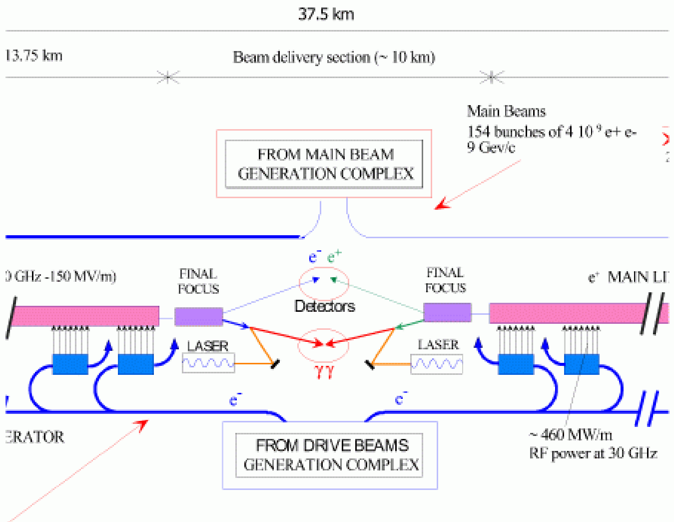
JLC



NLC



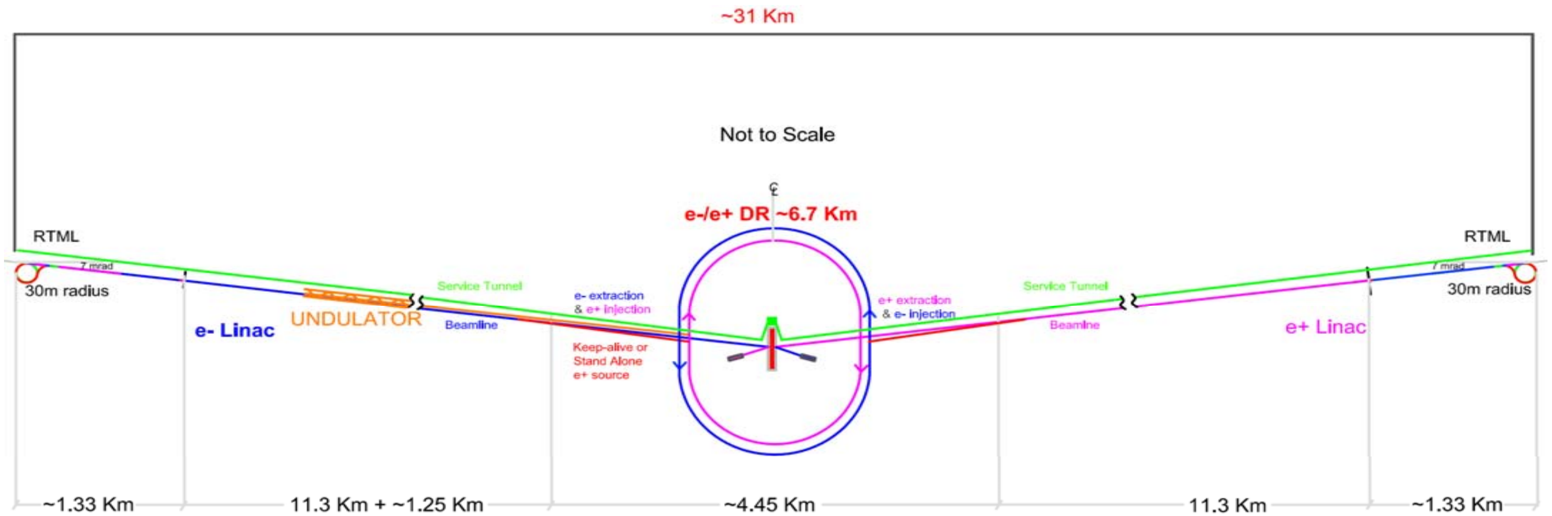
CLIC



International Linear Collider (ILC), 2004-

(Reference Design – Feb 2007)

2004- TESLA, NLC, JLC → ILC (based on TESLA superconducting technology



Schematic Layout of the 500 GeV Machine

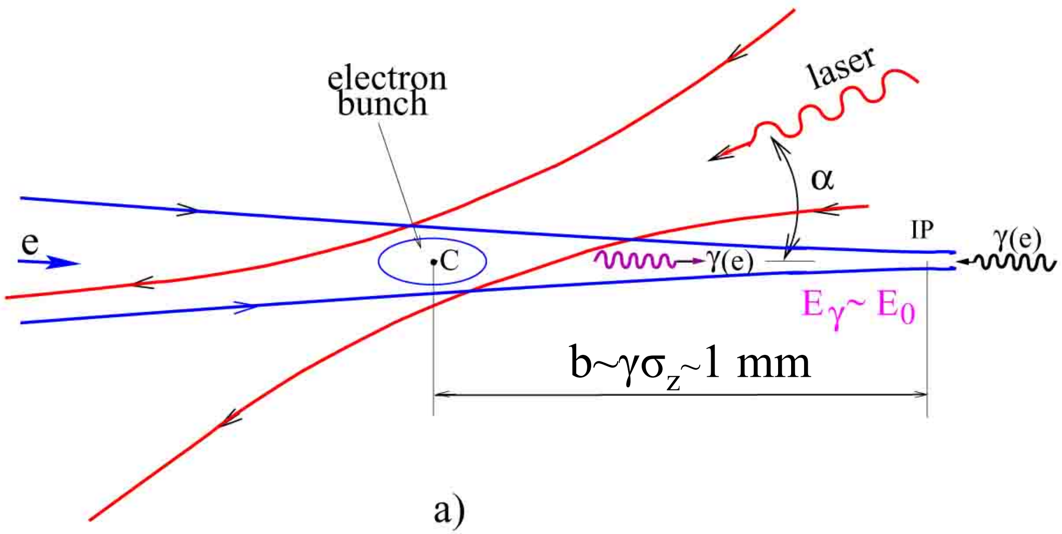
Two projects remain:

ILC- 2E= 500-1000 GeV (SC, G=30-35 MeV/m)

CLIC 500-3000 GeV (two-beam, G=100 MeV/m)

A decision on the construction depends on results from LHC

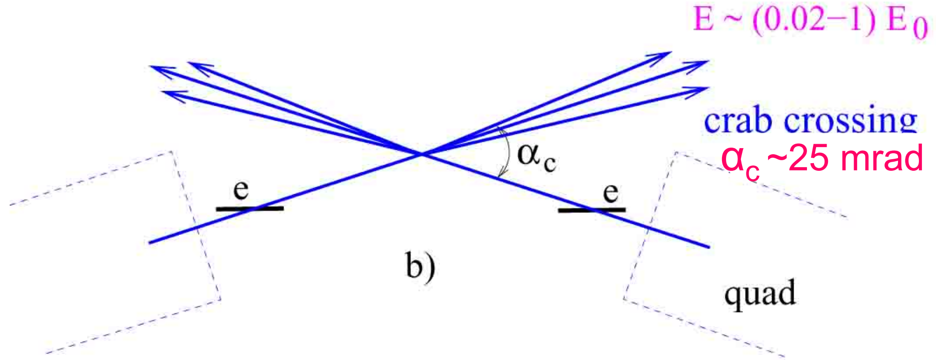
Scheme of $\gamma\gamma$, γe collider



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

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

$E_0 = 250$ GeV, $\omega_0 = 1.17$ eV
($\lambda = 1.06$ μm) $\Rightarrow$
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.

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

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

First publications (1981-83)

1. I.Ginzburg, G.Kotkin, V.Serbo, V.Telnov (GKST), On posibility of obtaining gamma-gamma, gamma-electron beams with high energy and luminosity, Prep.INP 81-50,Feb.1981, Pizma ZhETF 34 (1981) 514; [JETP Lett. 34(1982)91]
2. GKST, Nucl. Insrum.and Meth 205(1983) 47;
3. GKST+Panfil, Nucl. Insrum. and Meth A219 (1984) 5;

(2 and 3 – detailed description of PLC principles: kinematics, polarization effects, (ideal) luminosity spectra e.t.c.)

Very important (technical issues)

1. V.I.Telnov, Nucl. Insrum. Meth A294 (1990) 72; A355 (1995) 3 .

   (Removal of beams (crab crossing), beam collision effects limiting luminosity)
2. V.I.Telnov, (PHOTON99, May1999) Nucl.Phys.Proc.Suppl.82:359-366,2000.

   (“External” optical cavity for PLC) ,

Most full description of the PLC (in TESLA TDR)

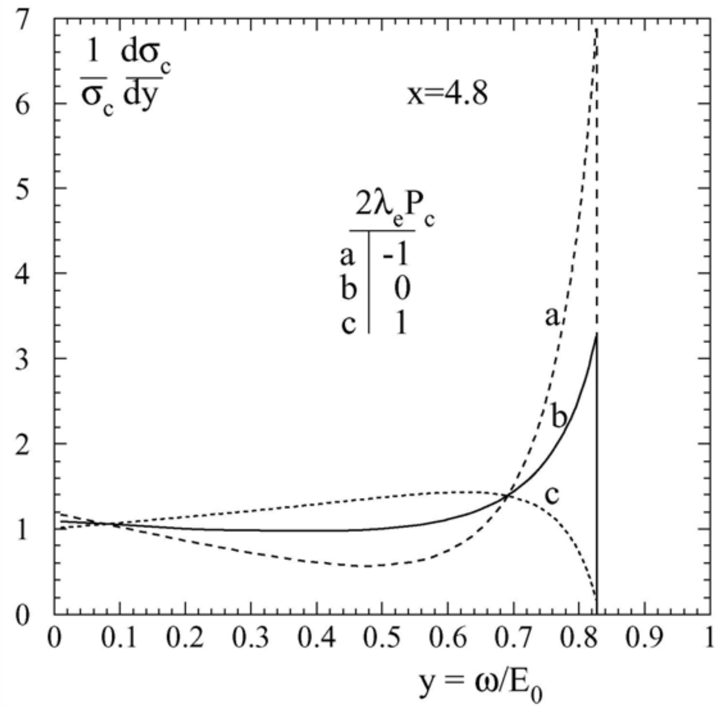
Badelek et al., Photon collider at TESLA (TESLA TDR), Int.J.Mod.Phys.A19: 5097-5186, 2004.

+more recent works (crossing angle, beamdump, optical scheme)

V.I. Telnov, Acta Physica Polonica B 37 (2006) 1049, physics/0604108

Electron to Photon Conversion

Spectrum of the Compton scattered photons

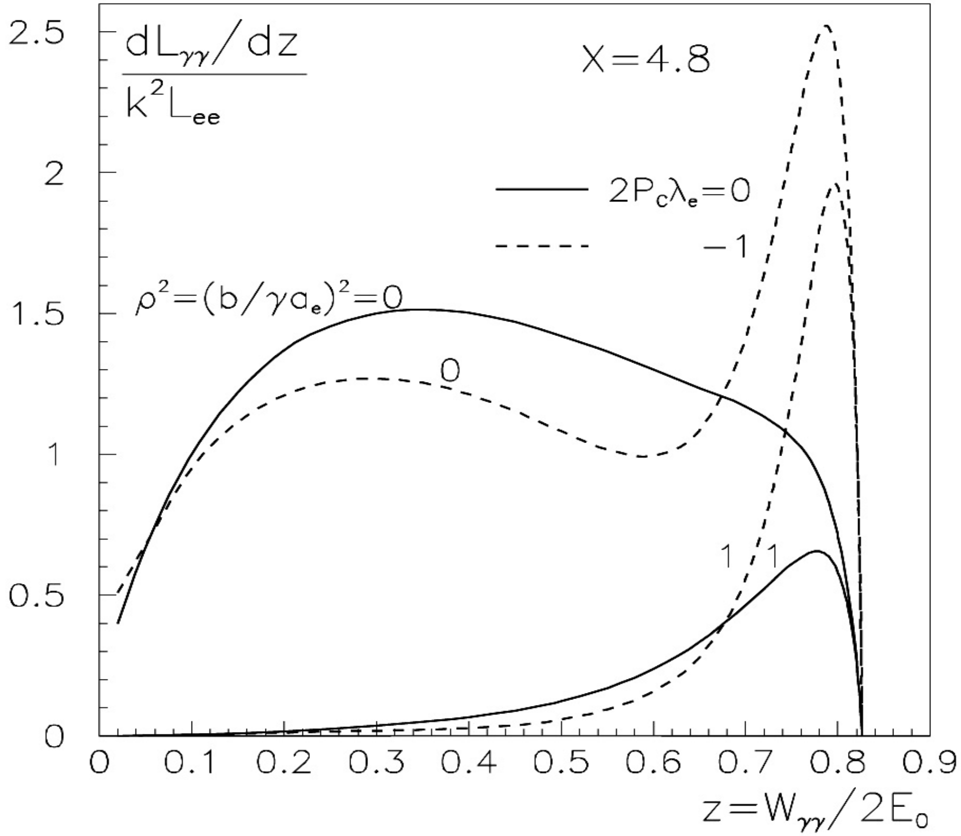


λ_e – electron longitudinal polarization
P_c – helicity of laser photons, $x \approx \frac{4E_0\omega_0}{m^2c^4}$

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

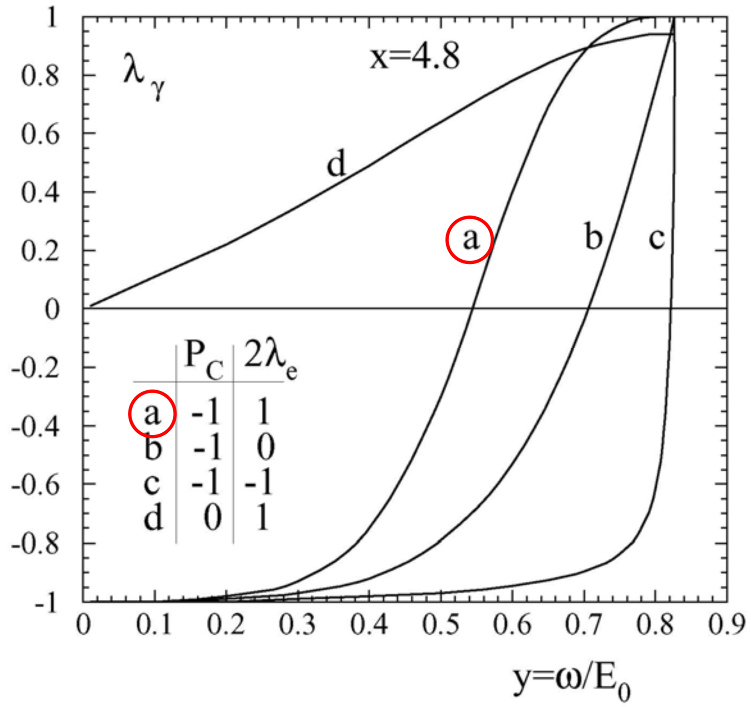
Ideal luminosity distributions, monohromatization

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



Electron polarization increases the $\gamma\gamma$ luminosity in the high energy peak up to a factor of ~3-4 (at large x).

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



Highest energy scattered photons are polarized even at λ_e=0 (see (b))

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

The cross section of the Higgs production

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

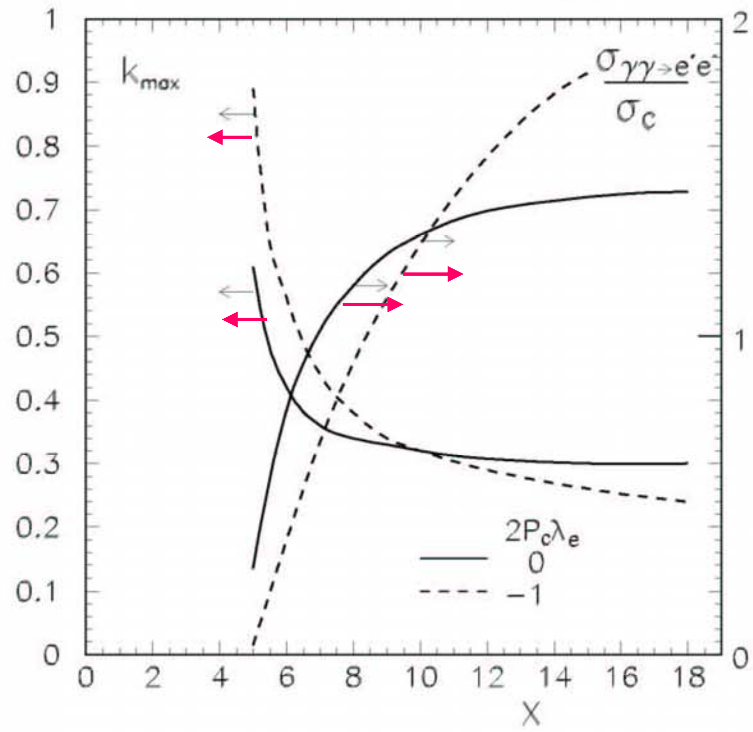
The cross section for main backgound

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

The electron polarization makes the region with a high polarization at ω~$\omega_{m)}$ wider (compare a and b).

e^+e^- pair creation

in the collisions of laser and high energy photons



The threshold of e^+e^- creation: $x = 4.8$, the optimum value.
Corrsponding wavelength $\lambda = 4.2 E_0[\mathrm{TeV}]\,\mu\mathrm{m}$.

$E_{\gamma,max}/E_0 \sim x/(x+1) \sim 0.82$

Laser $e \rightarrow \gamma$ conversion

The method of the Compton scattering of laser light off high energy electrons was known since 1964 (Arutyunian, Tumanian, Milburn) and was used since 1966 at SLAC and other labs with small $k=N_\gamma/N_e$.

For the photon collider one needs k~1 !

The required laser flash energy is about 3-10 J and ~1-3 ps durations and rep.rate similar to the linear collider (~10 kHz).

In 1981 we just believed that it will be possible just extrapolating the progress in the laser technique.

In 1985 D.Strickland and G.Mourou invented the chirped pulse technique which made the photon collider realistic.

For the supercondicting ILC one can use the external optical cavity which considerably decreases the required laser power and together with other modern laser techniques (diode pumping, adaptive optics, multilayer mirrors) makes the photon collider really technically feasible

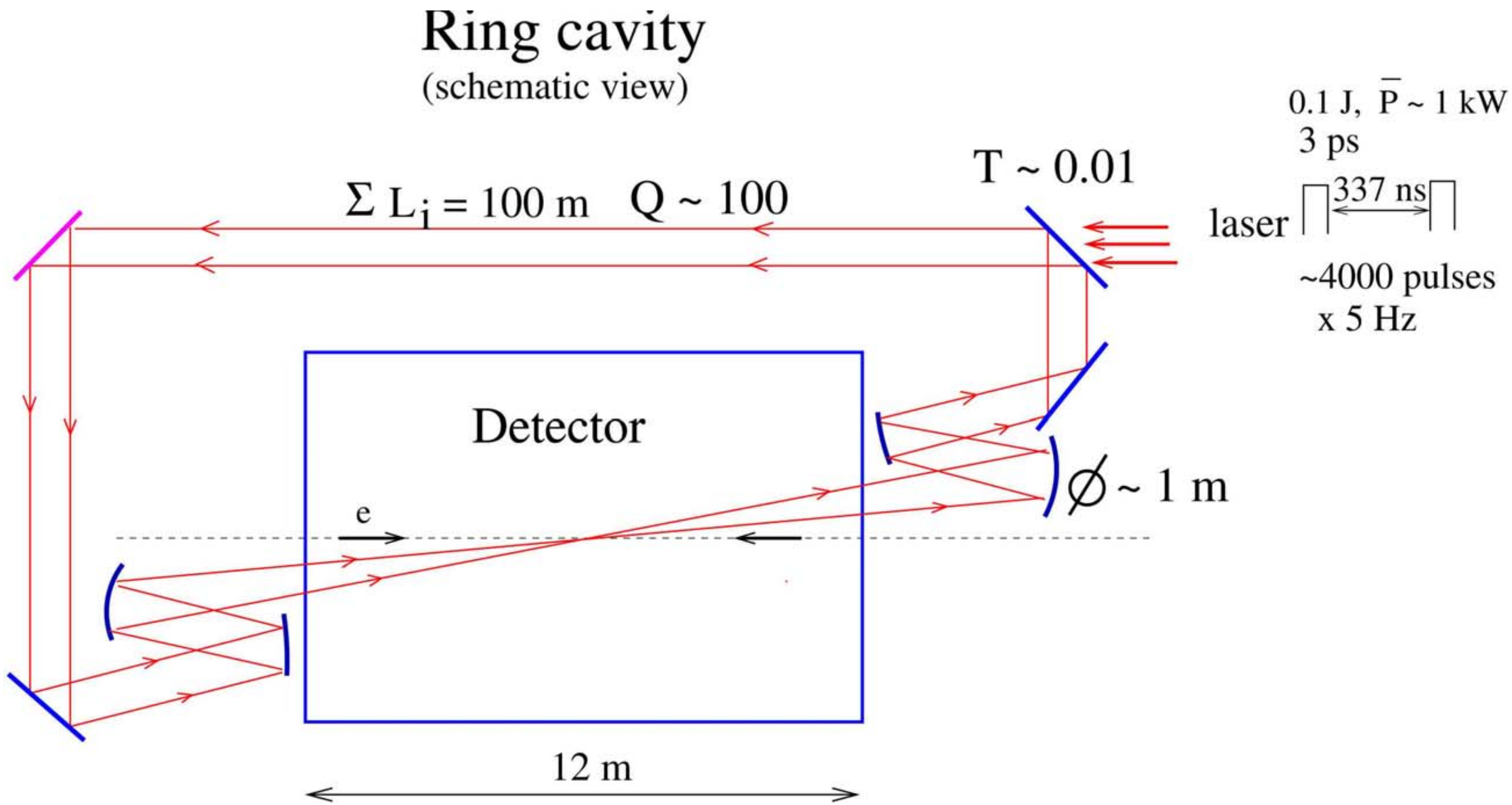
Laser system for PLC based on ILC

- Wavelength ~1 μm (good for 2E<0.8 TeV)
- Time structure Δct~100 m, 3000 bunch/train, 5 Hz (f_{col}~15 kH)
- 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 stacking 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 (or even more?).

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

Laser experts considered requirements to the optical cavity for the photon collider and by now have not revealed any show-stoppers. LLNL conclusion: technology is known, rough estimate of cost for the laser system is $20M.

At present there is a big activity on development of the laser pulse stacking cavities at Orsay, KEK, CERN, BNL, LLNL for

ILC polarimetry

Laser wire

Laser source of polarized positrons(ILC,CLIC,Super-B)

X-ray and γ-ray sources

PLC

All these developments are very helpful for the Photon collider.

Developments on laser technologies for PLC are reviewed at this workshop by Fabian Zomer.

New

Laser system for CLIC (V.Telnov, IWLC,2010)

Requirements to a laser system for a photon collider at CLIC

Laser wavelength	~ 1 μm
Flash energy	A~5 J
Number of bunches in one train	354
Length of the train	177 ns=53 m
Distance between bunches	0.5 nc
Repetition rate	50 Hz

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

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

Possible approaches to CLIC laser system

•FELs based on CLIC drive beams.

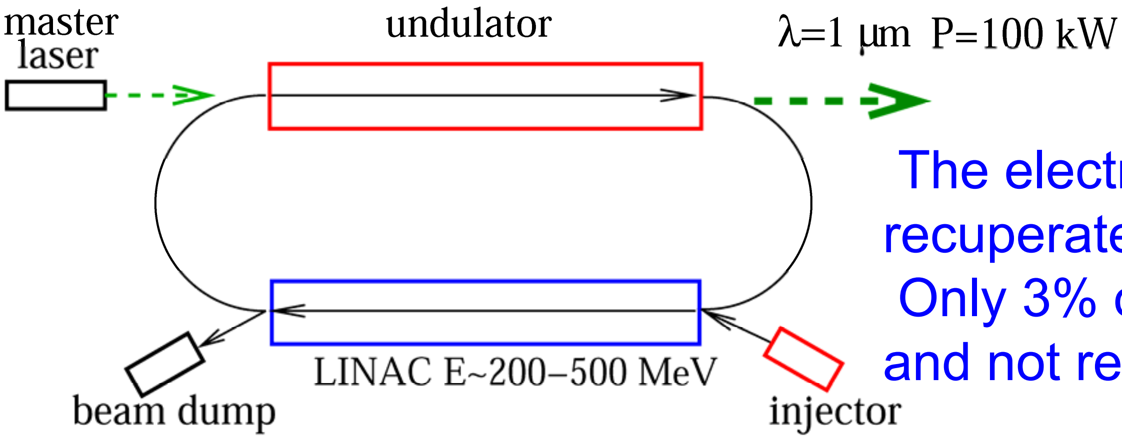
CLIC drive beams have not enough energy to produce the required FEL flashes. In addition, the laser pulse should be several times shorter than the CLIC drive bunch.

Solid state lasers pumped by diodes.

Storage time of the laser medium is about 1 ms. One laser trains contain the energy about 2 kJ, efficiency of diode pumping about 20%, therefore the total power of diodes should be P~2*2000/0.001/0.25~20 MW. At present, the cost of diodes for the laser system will be ~$O(100)$ M$. Experts say that such technology will be available only in one decade. LLNL works in this direction for laser fusion applications.

Suggestion:

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



The electron beam energy can be recuperated using SC linac.
Only 3% of energy is lost to photons and not recuperated.

With recuperation and 10% wall plug RF efficiency the total power consumption of the electron accelerator from the plug will be about 1-2 MW only.

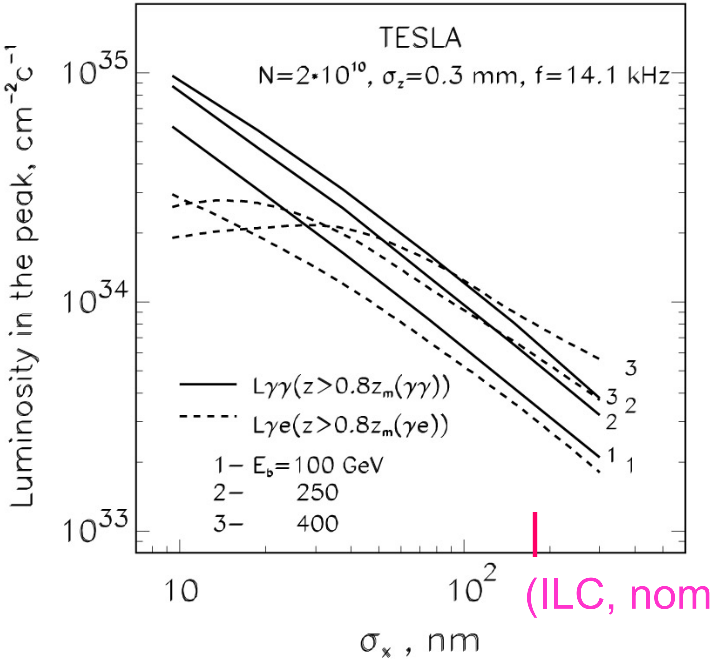
The rest past of the laser system is the same as with solid state lasers with diode pumping.

The FEL pumped solid state laser with recuperation of electron beam energy is very attractive approach for short linear colliders, such as CLIC.

Luminosities at the photon collider

Collision effects, restricting the luminosit

- Coherent pair creation ($\gamma\gamma$)
- Beamstrahlung (γe)
- Beam-beam repulsion (γe)



(ILC, nom)

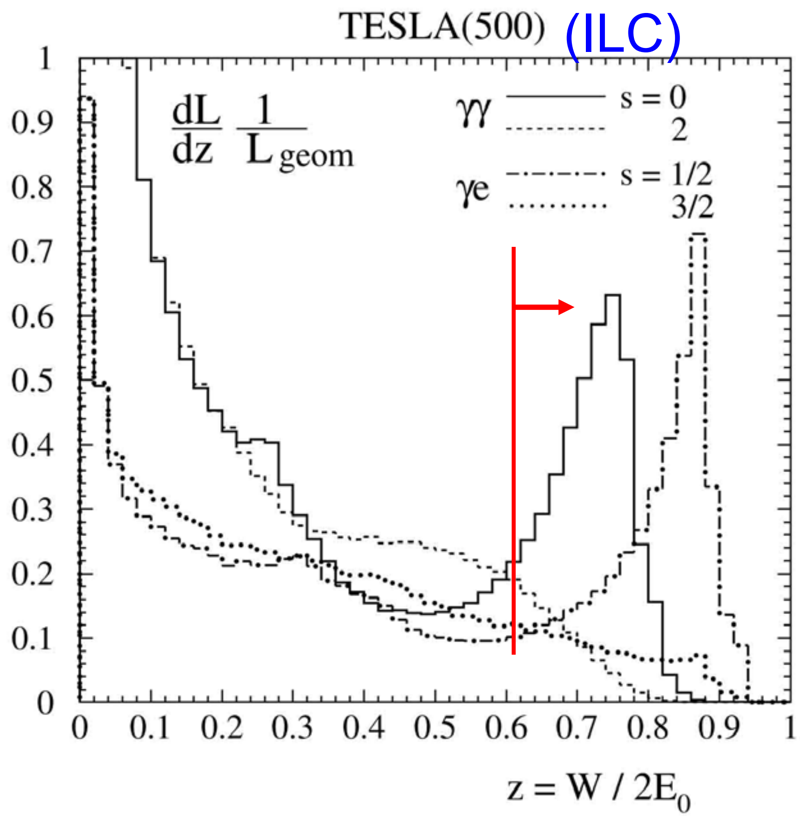
Simulations show that at ILC the collision effects are not important for $\gamma\gamma$ collisions (at 2E<1 TeV). $L_{\gamma\gamma}$ is determined by the geometric electron-electron luminosity and can be higher by one order of magnitude than that with nominal ILC beams (obtained in DRs)

The γe luminosity in the high energy peak is limited by beamstrahlung and beam repulsion.

So, one needs transverse beam emittances: ε_{nx}, ε_{ny} as small as possible.

Realistic luminosity spectra ($\gamma\gamma$ and γe)

(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 the nominal ILC beams (from DR)

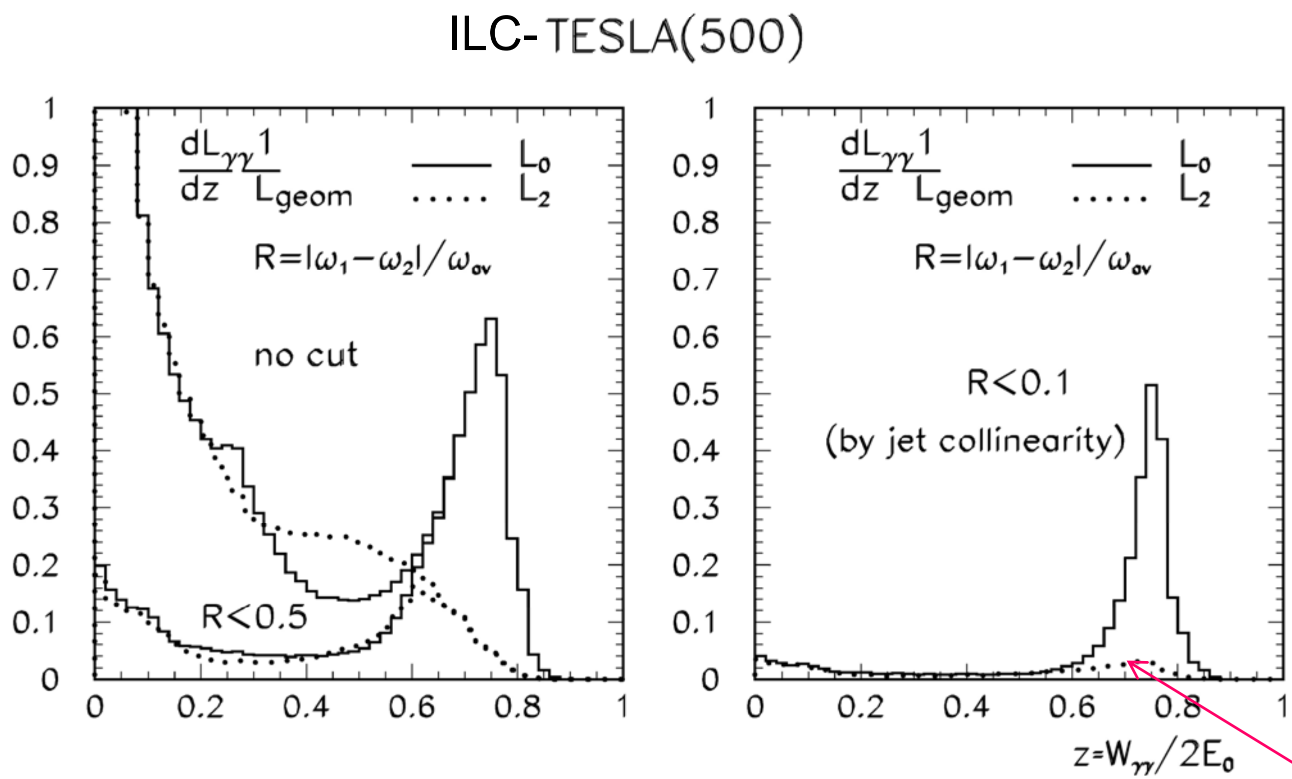
$L_{\gamma\gamma}(z>0.8z_m) \sim 0.2 L_{e+e-}(nom)$

In the general case, at the ILC

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

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

Realistic luminosity spectra at the PLC ($2\lambda_e$=0.85)



$\gamma\gamma$

$\gamma\gamma$ luminosity with J=2 is smaller than that with J=0 by factor of 10-20 (that is very important for extraction of the Higgs(130)

How to increase the luminosity?

Damping rings vs electron guns.

So, with nominal electron beams after DR the $\gamma\gamma$ luminosity at $z>0.8z_m$ is by a factor of 5 lower than e^+e^- luminosity. That is acceptable since typical $\gamma\gamma$ cross sections are by one of magnitude larger than in e+e- collisions.

Nevertheless, it is desirable to increase $\gamma\gamma$ luminosity as soon as it is not limited by fundamental factor.

Natural questions:

Why we need damping rings for the photon collider, is it possible to use electron beams directly from electron guns?

At present "NO", because beams from DR have smaller product of transverse emittances. The ratio of luminosities

L(DR)/ L(RFguns,unpol)~ 7-12
L(DR)/ L(DCguns,pol) ~ 100

The last number is so large because polarized electron RF-guns with low emittance do not exist yet (only DC guns).

Therefore until now DRs were considered as a source of polarized electrons for the PLC.

What to do?

First of all, it is necessary to develop polarized RF guns with low emittances.

If their emittances will be determined by space charge effects (as in unpolarized RF-guns)

L(DR)/ L(RFguns,unpol)~ 3

This is better, but still the luminosity is higher with DRs, new ideas are needed.

Longitudinal emittances

Longitudinal emittance is the product of the $\varepsilon_{nz} \approx (\sigma_E/mc^2)\sigma_z$
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

$$\varepsilon_{nz} \sim 2 \cdot 10^{-3} \text{ cm},$$

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?

New A proposed method (Telnov, IWLC10,CERN)

Let us combine many low charge, low emittance beams from a photo-gun to one bunch (3 nC for ILC) using some differences in their energies. The longitudinal emittance increases approximately proportionally to the number of combined bunches while the transverse emittance (which is important for us) remains almost constant.

It is assumed that at the ILC initial micro bunches with small emittances are produced as trains by one electron photo-gun.

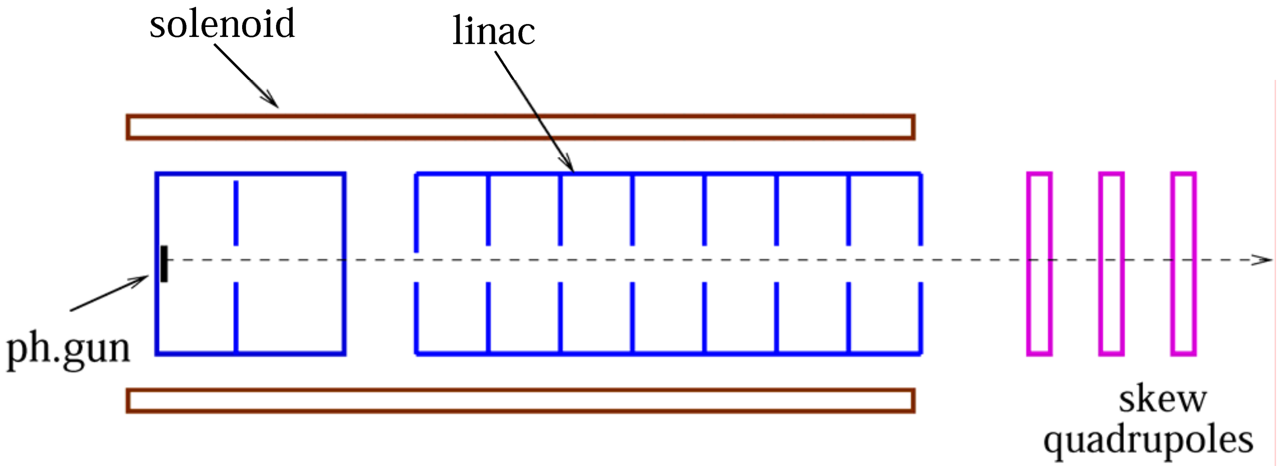
In the CLIC case the distance between bunches is very small therefore micro bunches are produced by many separate photo-guns.

Each gun is followed by round-to-flat beam transformer (RFT). RFT does not change the product of transverse emittances, but it is easier to conserve emittances manipulating with flat beams in the horizontal plane.

Below the scheme for the ILC case is considered.
(details see my talk at IWLC2010, CERN, October 2010)

Round to flat transformer (RFT)

A system of RF gun inside the solenoid and following skew quadrupoles can transform a round beam (from an electron gun) to a flat beam with an arbitrary aspect ratio.

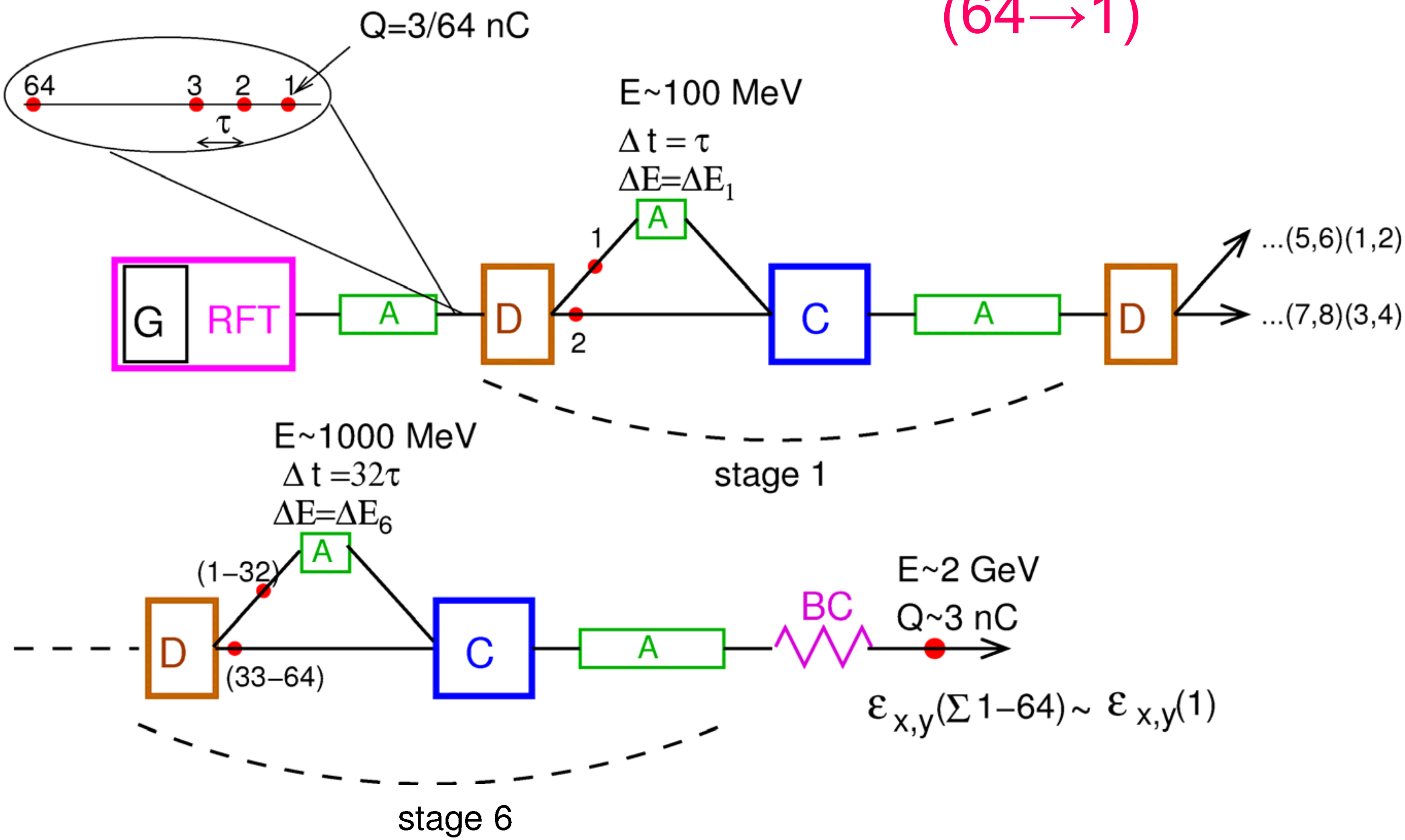


After such transformation $\varepsilon_{nx}\varepsilon_{ny}=\varepsilon^0_{nx}\varepsilon^0_{ny}=(\varepsilon^G_n)^2$=const

The ratio $R=\dfrac{\varepsilon_{nx}}{\varepsilon_{ny}}=100$ was demonstrated at FNAL and this is not the limit.

Scheme of combining one bunch from the bunch train (for ILC)

(64→1)

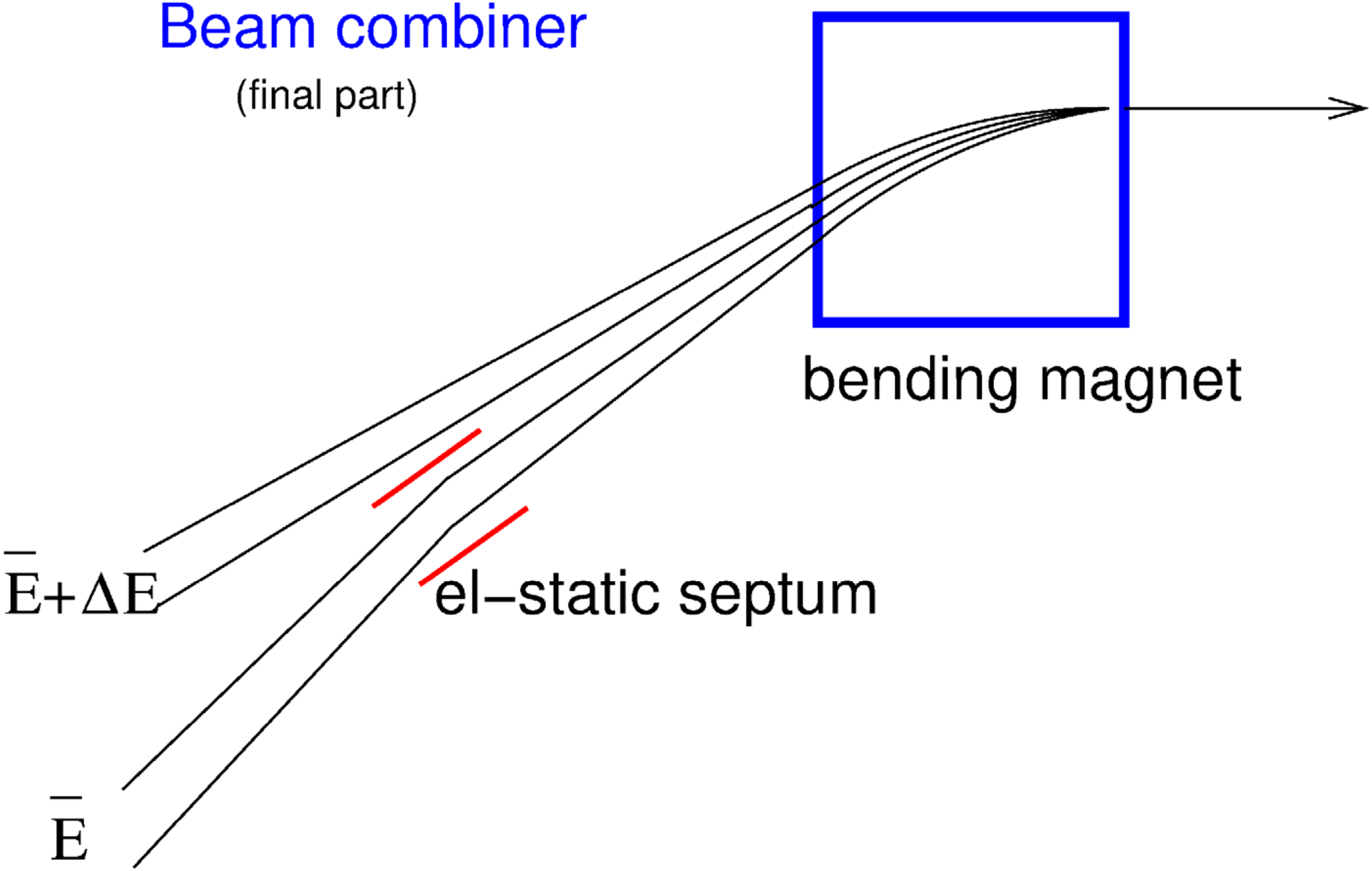


G –photogun, A –RF–cavities (accel), RFT –round to flat transformer,

D –deflector, C –beam combiner, BC –bunch compressor

Beam combiner

(final part)



Emittances in RF-guns

There are two main contribution to transverse emittances in RF guns:
1. Space charge induced normalize emittance;
2. Thermal emittance.

The space charge emittance $\varepsilon_{sc} \sim 10^{-4}$ Q[nC] cm

The thermal emittance $\varepsilon_{th} \sim 0.5 \cdot 10^{-4}$ R[mm], cm

Assuming $R^2 \propto Q$ and R=1 mm at 1 nC, we get for Q=3/64 nC

$$\varepsilon_{sc} \sim 0.5 \cdot 10^{-5} \text{ cm}, \ \varepsilon_{th} \sim 10^{-5}$$

$$\to \varepsilon_{n,} \sim 10^{-5} \text{ cm}$$

After RFT with the ratio 100

$$\varepsilon_{nx} \sim 10^{-4} \text{ cm}, \ \varepsilon_{ny} \sim 10^{-6} \text{ cm.}$$

Luminosities

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,

(β_x is larger for DR case due to chromo-geometric abber. for large transverse emittances)

The ratio of geometric luminosities

$$L_{RFgun}/L_{DR}=12\sim10$$

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

In the case of unpolarized RF-guns the effective luminosity will be higher than with DR by a factor of 3-4.

Comparison of polarized and unpolarized beams

$\rho=(b/\gamma)\sigma_y$

The following cases are considered:

2E=200 GeV, x=1.8

polarized 85%, $\rho=3$
unpolarized, $\rho=3$

2E=500 GeV, x=4.5

polarized 85%, $\rho=3$
unpolarized, $\rho=3$

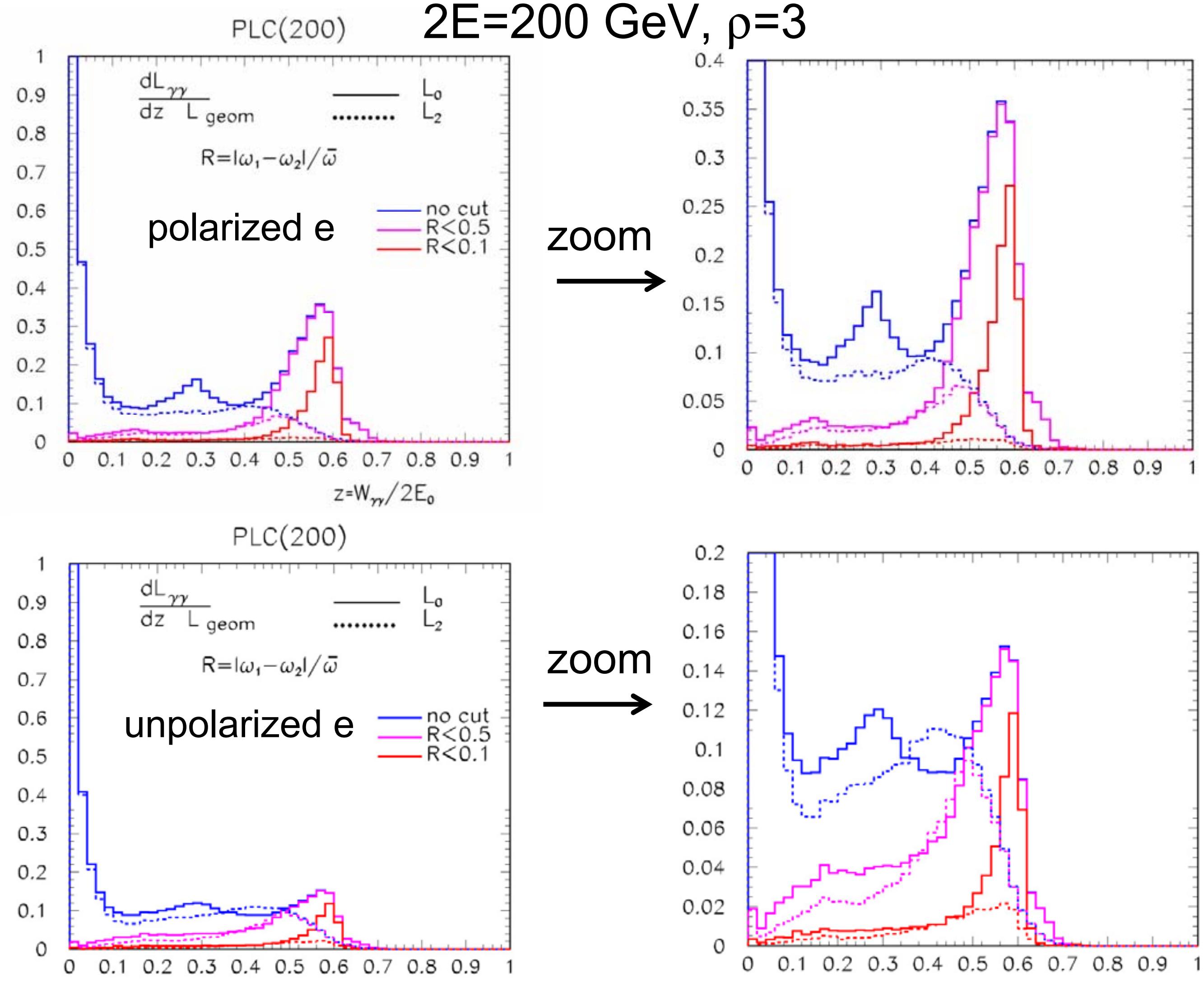
Laser photons have 100% helicity in all examples.

To see better the luminosity with central collisions a cut on the parameter $R=|\omega_1-\omega_2|/\langle\omega\rangle$ is applied.

The increased CP-IP distance b is used in order to suppress low $W_{\gamma\gamma}$ luminosity (the case $\rho=3$).

Comparison of polarized and unpolarized electron beams,

2E=200 GeV, ρ=3



at $z>0.85z_m$

$L^p_0/L^p_2\sim20$

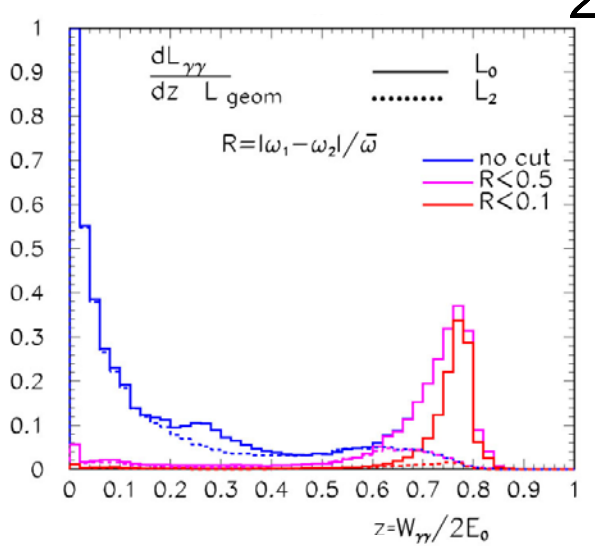
$L^{up}_0/L^{up}_2\sim3.55$

L^p_0/L^{up}_0=2.2 and L_0/L_2 suppression is higher 20/3.5=5.7 times for pol. beams.

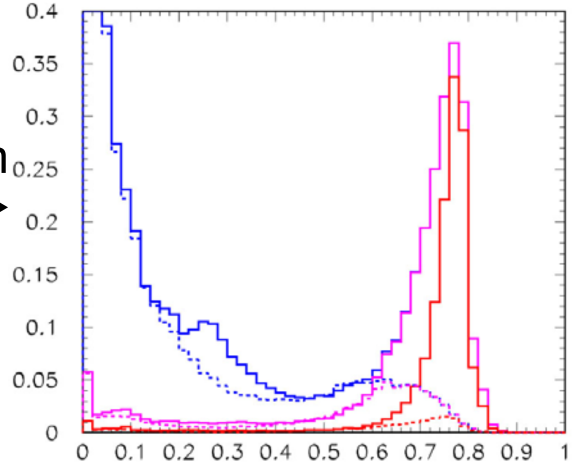
Nevertheless, γγ collisions with unpol. electrons have rather good polarization properties, sufficient for study of many processes.

Comparison of polarized and unpolarized electron beams

$2E=500$, $\rho=3$

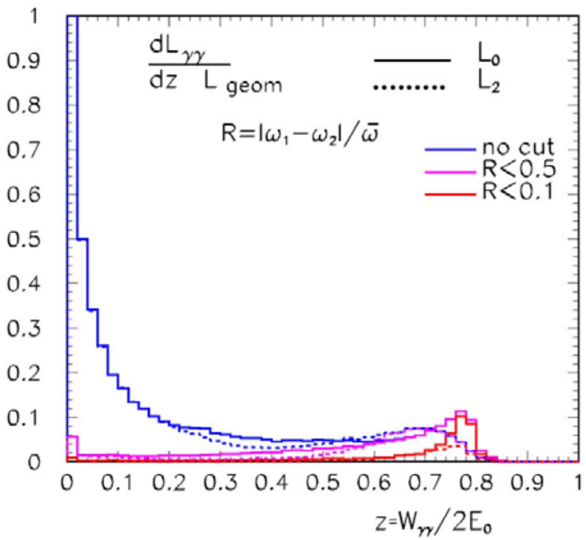


zoom →

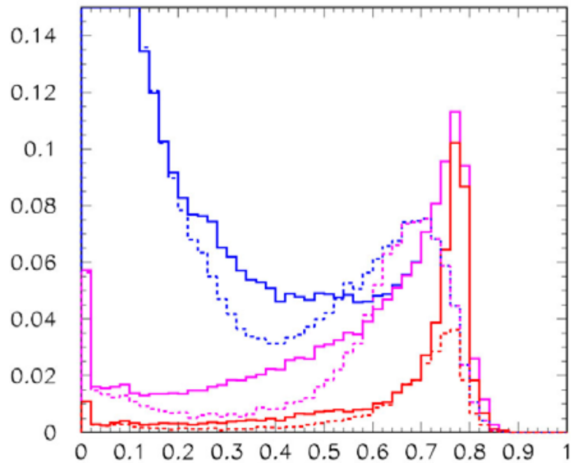


at $z>0.85z_m$

$L^p{}_0/L^p{}_2\sim 20$



zoom →



$L^{up}{}_0/L^{up}{}_2\sim 2.5$

$L^p{}_0/L^{up}{}_0=3.3$ and L_0/L_2 suppression is higher 20/2.5=8 times for pol. beams.

Discussion

Polarized RF-guns

Having polarized RF guns with emittances similar to existing unpolarized guns we could obtain the $\gamma\gamma$ luminosity ~10 times higher than that with ILC DRs (all polarization characteristics are similar).

Unpolarized RF-guns

Already with existing RF guns we can get the $\gamma\gamma$ luminosity higher than with DR by a factor of 4.5-3 for 2E=200-500 GeV, but L_0/L_2 in the high energy peak will be only 3.5-2.5 instead of 20 for polarized beams, which is acceptable (the case of H(120) should be checked).

So, the PLC does not need damping rings!

The above dreams should be proved by realistic consideration-optimization, also polarized RF-guns are needed (very desirable).

Physics at PLC

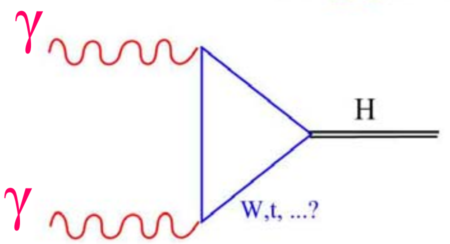
Physics at PLC was discussed so many times (>1000 papers) that it is difficult to add something essential. Most of examples are connected with production of the Higgs bosons or SUSY particles.

At present, SUSY is almost closed by LHC, and existence of the Higgs boson will be checked very soon.

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

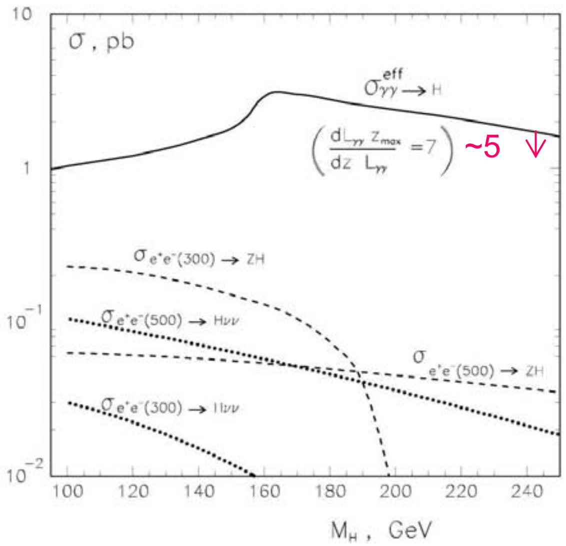
Some examples of physics at PLC

Higgs boson



Very sensitive to heavy charge particles in the loop.

Cross sections of the Higgs boson in $\gamma\gamma$ and e^+e^- collisions



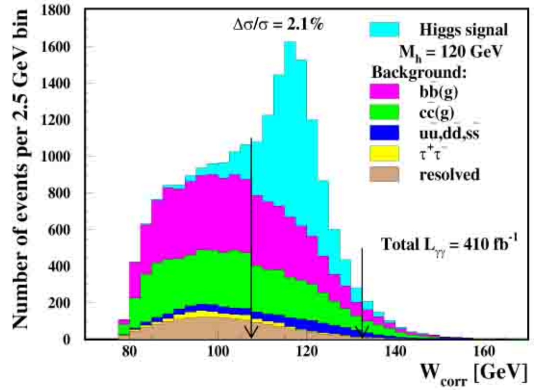
$$\dot{N}_{\gamma\gamma \to H} = L_{\gamma\gamma} \times \frac{dL_{\gamma\gamma} M_H}{dW_{\gamma\gamma} L_{\gamma\gamma}} \frac{4\pi^2 \Gamma_{\gamma\gamma}(1+\lambda_1\lambda_2)}{M_H^3}$$

At ILC

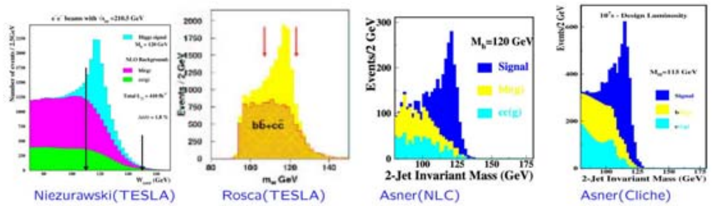
$$\frac{N(\gamma\gamma \to H)}{N(e^+e^- \to H + X)} \sim 1 - 10$$

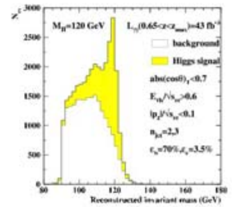
For M_H=115-250 GeV

realistic simulation P.Niezurawski et al



(previous analyses)





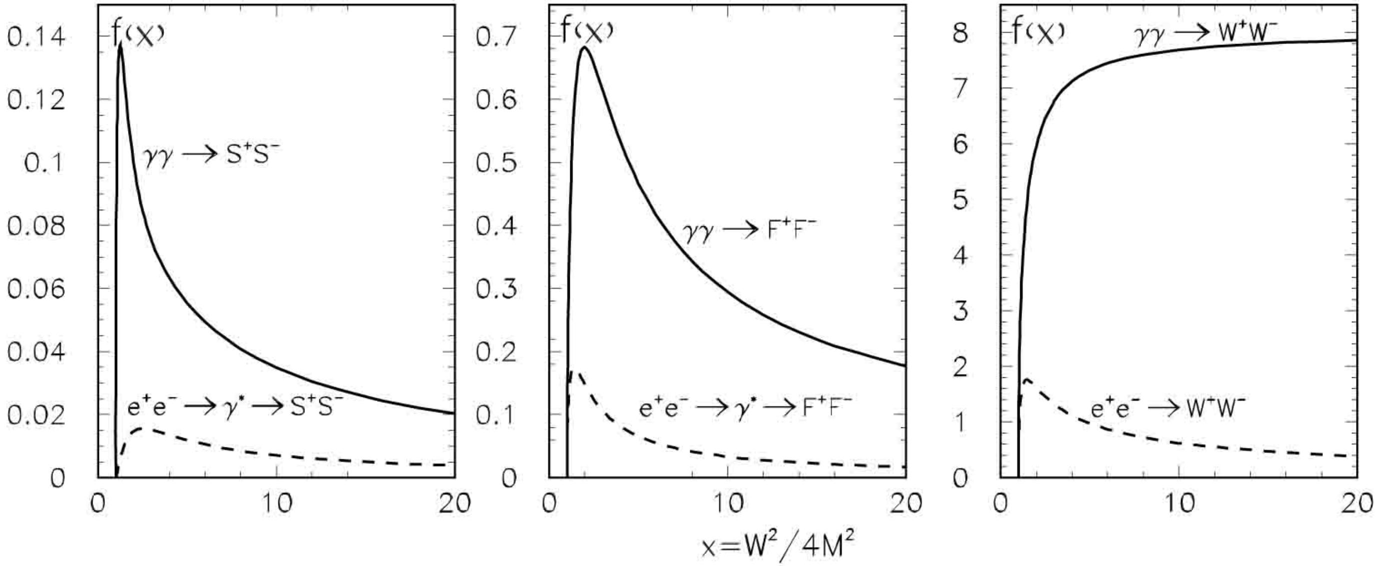
S.Soldner-Rembold

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

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

(S (scalars), F (fermions), W (W-bosons);

$\sigma = (\pi\alpha^2/M^2)f(x)$, beams unpolarized)



unpolarized beams

So, typical cross sections for charged pair production in $\gamma\gamma$ collisions is larger than in e^+e^- by one order of magnitude

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:

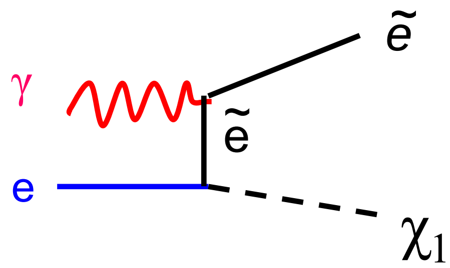
in e$^+$e$^-$ collisions $M_{H,A}^{max} \sim E_0$ (e$^+$e$^-$ $\to H + A$)
in $\gamma\gamma$ collisions $M_{H,A}^{max} \sim 1.6 E_0$ ($\gamma\gamma \to H(A)$)

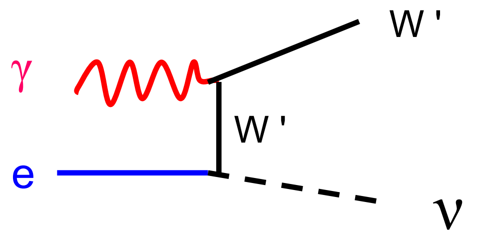
For some SUSY parameters H,A can be seen only in $\gamma\gamma$
(but not in e+e- and LHC)

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):

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





Gold-plated processes at photon colliders

Reaction	Remarks
$\gamma\gamma \to h_0 \to \bar{b}b$	$\mathcal{SM}$ (or $\mathcal{MSSM}$) Higgs, $M_{h_0} < 160$GeV
$\gamma\gamma \to h_0 \to WW(WW^*)$	$\mathcal{SM}$ Higgs, 140GeV $< M_{h_0} <$ 190GeV
$\gamma\gamma \to h_0 \to ZZ(ZZ^*)$	$\mathcal{SM}$ Higgs, 180GeV $< M_{h_0} <$ 350GeV
$\gamma\gamma \to h_0 \to \gamma\gamma$	$\mathcal{SM}$ Higgs, $M_{h_0} < 150$GeV
$\gamma\gamma \to H, A \to \bar{b}b$	$\mathcal{MSSM}$ heavy Higgs, for intermediate $\tan\beta$
$\gamma\gamma \to \tilde{f}\bar{\tilde{f}},\ \tilde{\chi}_i^+\tilde{\chi}_i^-,\ H^+H^-$	large cross sections, possible observ. of FCNC
$\gamma\gamma \to S[\tilde{t}\bar{\tilde{t}}]$	$\tilde{t}\bar{\tilde{t}}$ stoponium
$\gamma e \to \tilde{e}^-\tilde{\chi}_1^0$	$M_{\tilde{e}^-} < 0.9 \times 2E_0 - M_{\tilde{\chi}_1^0}$
$\gamma\gamma \to W^+W^-$	anomalous W interact., extra dimen.
$\gamma e^- \to W^-\nu_e$	anomalous W couplings
$\gamma\gamma \to WW + WW(ZZ)$	strong WW scatt., quartic anom. W, Z coupl.
$\gamma\gamma \to t\bar{t}$	anomalous top quark interactions
$\gamma e^- \to \bar{t}b\nu_e$	anomalous Wtb coupling
$\gamma\gamma \to$ hadrons	total $\gamma\gamma$ cross section
$\gamma e^- \to e^-X$ and $\nu_e X$	structure functions (pol. and unpol.)
$\gamma g \to \bar{q}q,\ \bar{c}c$	gluon distribution in the photon
$\gamma\gamma \to J/\psi\, J/\psi$	QCD Pomeron

Physics motivation: summary

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
4. higher precision for some phenomena
5. different type of reactions (different dependence on theoretical parameters)

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

Present status of PLC

"Be or not to be" for the Photon collider is equivalent to the same question for the linear e+e- collider.

Physics community made a clear statement many years ago that any linear collider should be compatible with the photon collider.

In order to minimize the cost and get approval ILC and CLIC managements push forward baseline designs without any options. However everybody understand that after approval projects will be carefully reconsidered and all options will taken into account.

The best time for the start of the LC construction was between 1995 and 2001. Now we should wait results from LHC.

Conclusion remarks:

$\gamma\gamma$ physics: past, present and future

Past and present:

$\gamma^*\gamma^* \to X$ at e+e+ storage rings:

$$dn_\gamma \sim 0.03\, d\omega/\omega$$

$$L_{\gamma\gamma} << L_{e+e-}$$

$$W_{\gamma\gamma} << 2E_0$$

1970 $e^+e^- \to e^+e^-e^+e^-$ Novosibirsk

1972 $\mu^+\mu^-$ Frascaty

1979 η' SLAC

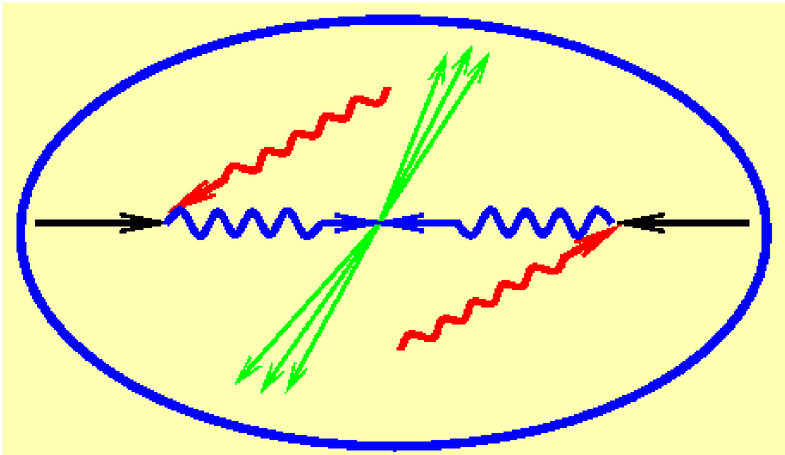
1980 – now: several hundreds of papers from all e+e- colliders. Physics is quite interesting but not as e+e- due to lower energy and luminosity.

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
2001 Snowmass: LC is the next HEP project
2004 Technology was chosen, the first ILC workshop
2006 ILC reference design
2007-12 ILC technical pre-design
2016-25 ? construction of ILC (or CLIC)
2025 ? beginning of e^+e^- experiments at ILC
~2030 ? beginning of $\gamma\gamma$ experiments?

This is the work for several generations !



I hope the photon collider

(e+e-,e-e-,$\gamma\gamma$,γe)

will be built sometime and help us to understand new particle physics phenomena!