Siberian Branch of Russian Academy of Science
BUDKER INSTITUTE OF NUCLEAR PHYSICS

V. Telnov

PHOTON COLLIDER ($\gamma\gamma$, γe)AT TESLA

BUDKER INP 2001-72

http://www.inp.nsk.su/publications

Novosibirsk
2001

Photon collider ($\gamma\gamma$, γe) at TESLA [*]

Valery Telnov
Institute of Nuclear Physics, 630090 Novosibirsk, Russia [†]

Abstract

Photon colliders ($\gamma\gamma$, γe) are based on backward Compton scattering of laser light off the high energy electrons in linear colliders. Recently the Technical Design Report of the linear collider TESLA has been published. In this paper physics program, possible parameters and some technical aspects are discussed.

1 Introduction

Recently, the ECFA Panel in Europe and the Snowmass Study on Future of High Energy Physics in US have recommended the linear collider on the energy about 500 GeV as the next large HEP project.

The unique feature of the e^+e^- Linear Colliders is the possibility to construct on its basis a Photon Collider using the process of the Compton backscattering of laser light off the high energy electrons [1]-[4]. This option is considered now for all linear colliders projects. In March 2001 the Technical Design of the linear collider TESLA on the energy 90–800 GeV has been published [5]. The Photon Collider has been included in the project, though many technical aspects, especially the laser system, should be developed in the next 2–3 years. So, it is very likely that in about one decade physicists will get a new very powerful instrument for study of matter: e^+e^-, $\gamma\gamma$, γe, e^-e^- collider.

Discussion of the photon collider scheme and basic principles can be found elsewhere [2]-[6]. In this paper physics, parameters of the TESLA photon collider and possible laser schemes are discussed shortly.

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[*] Talk at Intern. Conf. on the Structure and Interactions of the Photon, incl. the 14th Intern. Workshop on Photon-Photon Collisions – PHOTON2001, Ascona, Switzerland, Sept.2-7, 2001

[†] email:telnov@inp.nsk.su

2 Physics

Physics in e^+e^- and $\gamma\gamma$, γe collisions is quite similar, however, reactions are different and can give complementary information. Some phenomena can best be studied at photon colliders due to better accuracy (larger cross sections or unique reactions, such as $\gamma\gamma \to Higgs$) or due to larger accessible masses: a single resonance in $\gamma\gamma$ and γe or a pair of light and heavy particles in γe collisions. As we will see below the $\gamma\gamma$ luminosity in the high energy part of spectra at TESLA can be about 30 % of the e^+e^- luminosity. Taking into account that typical cross sections in $\gamma\gamma$ collisions are higher than those in e^+e^- collisions by about one order of magnitude [4, 8, 5] the number of "interesting" events at the photon collider will be even higher than in e^+e^- collision. So, it is quite clear from general considerations that Photon Collider can complement in an essential way the physics program of the TESLA e^+e^- mode. A short list of physics processes for the photon collider is presented in Table 1 [7]. More detail consideration of the physics program at photon colliders can be found elsewhere [7, 5].

Table 1: Gold-plated processes at photon colliders

Reaction	Remarks
$\gamma\gamma \to h_0 \to \bar{b}b, \gamma\gamma$	$M_{h_0} < 160$ GeV
$\gamma\gamma \to h_0 \to WW(WW^*)$	$140 < M_{h_0} < 190$ GeV
$\gamma\gamma \to h_0 \to ZZ(ZZ^*)$	$180 < M_{h_0} < 350$ GeV
$\gamma\gamma \to H, A \to \bar{b}b$	$\mathcal{MSSM}$ heavy Higgs
$\gamma\gamma \to \bar{\tilde{f}}\tilde{f}, \tilde{\chi}_i^+\tilde{\chi}_i^-, H^+H^-$	supersymmetric particles
$\gamma\gamma \to S[\bar{\tilde{t}}\tilde{t}]$	$\bar{\tilde{t}}\tilde{t}$ stoponium
$\gamma e \to \tilde{e}^-\tilde{\chi}_1^0$	$M_{\tilde{e}^-} < 0.9 \times 2E_0 - M_{\tilde{\chi}_1^0}$
$\gamma\gamma \to W^+W^-$	anom. W inter., extra dim.
$\gamma e^- \to W^-\nu_e$	anom. W couplings
$\gamma\gamma \to WW + WW(ZZ)$	strong WW scattering
$\gamma\gamma \to t\bar{t}$	anom. t-quark interactions
$\gamma e^- \to \bar{t}b\nu_e$	anom. Wtb coupling
$\gamma\gamma \to$ hadrons	total $\gamma\gamma$ cross section
$\gamma e^- \to e^-X$ and $\nu_e X$	struct. functions
$\gamma g \to \bar{q}q, \bar{c}c$	gluon distr. in the photon
$\gamma\gamma \to J/\psi\, J/\psi$	QCD Pomeron

3 Parameters of the Photon collider at TESLA

The parameters of the photon collider at TESLA for the energy of electron beams $2E_0 = 200$, 500 and 800 GeV are presented in Table 2. For comparison the e^+e^- luminosity at TESLA is also included. It is assumed that the electron beams have 85% longitudinal polarization and that the laser photons have 100% circular polarization. The thickness of the laser target is one Compton scattering length for $2E_0 = 500$ and 800 GeV and 1.35 scattering length for $2E_0 = 200$ GeV, so that $k^2 \approx 0.4$ and 0.55, respectively (k is the $e \to \gamma$ conversion coefficient). The laser wave length is 1.06 μm for all energies. The distance between conversion and interaction points is $b = \gamma\sigma_y$ for $2E_0 = 500$ and 800 GeV and $b = 2\gamma\sigma_y$ for $2E_0 = 200$ GeV. Simulation results presented below include nonlinear effects in the Compton scattering [10]. Corresponding parameters $\xi^2 = 0.15, 0.2, 0.4$ for $2E_0 = 200, 500, 800$ GeV, respectively. From Table 2 one can see that for the same energy $L_{\gamma\gamma}(z > 0.8z_m) \approx (1/3)L_{e^+e^-}$.

Table 2: Parameters of the photon collider at TESLA.

$2E_0$,GeV	200	500	800
λ_L [μm]/x	1.06/1.8	1.06/4.5	1.06/7.2
t_L/λ_{scat}	1.35	1	1
$N/10^{10}$	2	2	2
σ_z [mm]	0.3	0.3	0.3
$f_{rep} \times n_b$ [kHz]	14.1	14.1	14.1
$\gamma\epsilon_{x/y}/10^{-6}$ [m·rad]	2.5/0.03	2.5/0.03	2.5/0.03
$\beta_{x/y}$ [mm] at IP	1.5/0.3	1.5/0.3	1.5/0.3
$\sigma_{x/y}$ [nm]	140/6.8	88/4.3	69/3.4
b [mm]	2.6	2.1	2.7
L_{ee}(geom) [10^{34} cm^{-2}s^{-1}]	4.8	12	19
$L_{ee}(z > 0.65)$	0.03	0.07	0.095
$W_{\gamma\gamma,max}$ (GeV)	122	390	670
$L_{\gamma\gamma}(z > 0.8z_{m,\gamma\gamma})$ [10^{34}]	0.43	1.1	1.7
$W_{\gamma e,max}$ (GeV)	156	440	732
$L_{\gamma e}(z > 0.8z_{m,\gamma e})$ [10^{34}]	0.36	0.94	1.3
$L_{e^+e^-}$ [10^{34} cm^{-2}s^{-1}]	1.3	3.4	5.8

Simultaneously with $\gamma\gamma$ collisions there are also γe collisions with somewhat lower luminosity, so one can study both types of collisions simultaneously. Residual electron-electron luminosity is very small due to the beam repulsion.

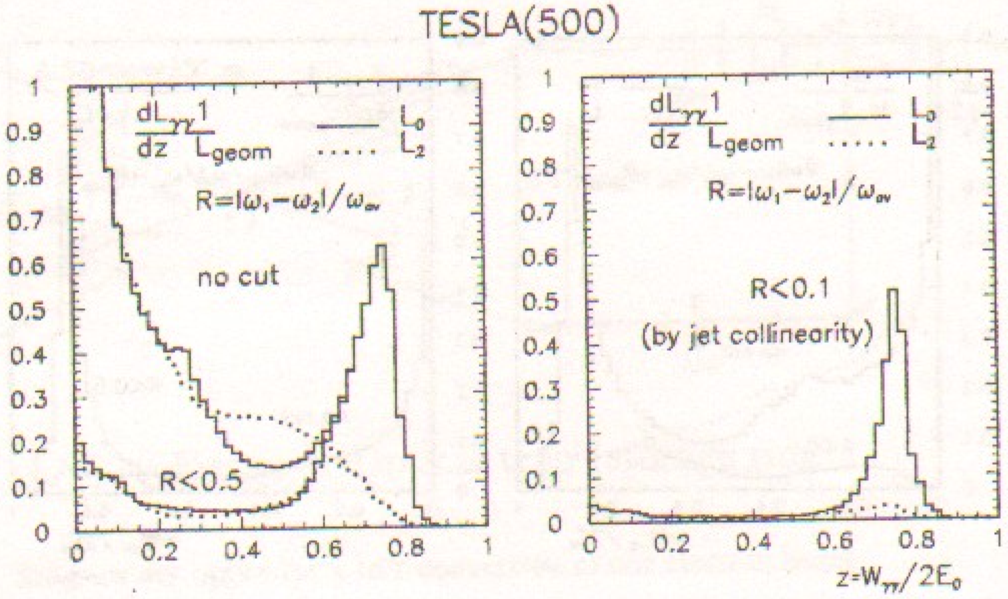

Figure 1: $\gamma\gamma$ luminosity spectra at TESLA(500). Solid line for total helicity of the two photons 0 and dotted line for total helicity 2.

The normalized $\gamma\gamma$ luminosity spectra for $2E_0 = 500$ GeV and 800, 200 GeV are shown in Fig. 1 and Fig. 2, respectively. The luminosity spectra are decomposed in two parts: with the total helicity 0 and 2. Fig. 1 shows also luminosity spectra with additional cuts on the longitudinal momentum of the produced system, which suppress the low energy luminosity to a low level. In the case of only two jets one can restrict the longitudinal momentum using the acollinearity angle between jets ($H \to b\bar{b}, \tau\tau$, for example).

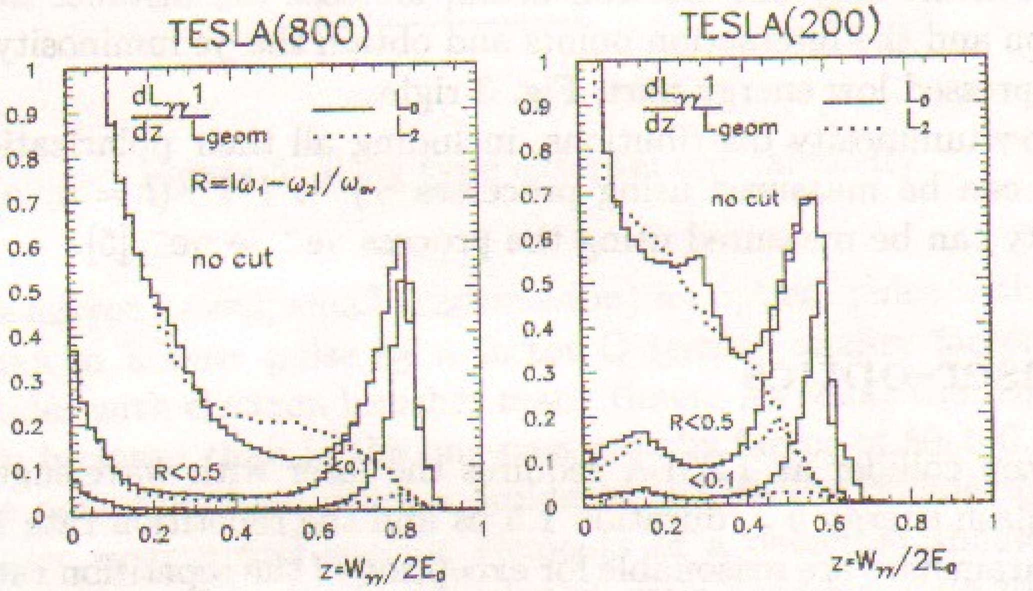

Figure 2: The $\gamma\gamma$ luminosity spectra at TESLA for $2E_0 = 800$ and 200 GeV (for Higgs(115))

The normalized γe luminosity spectra for $2E_0 = 500$ GeV and parameters from Table 2 are shown in Fig. 3-left. For dedicated γe experiments

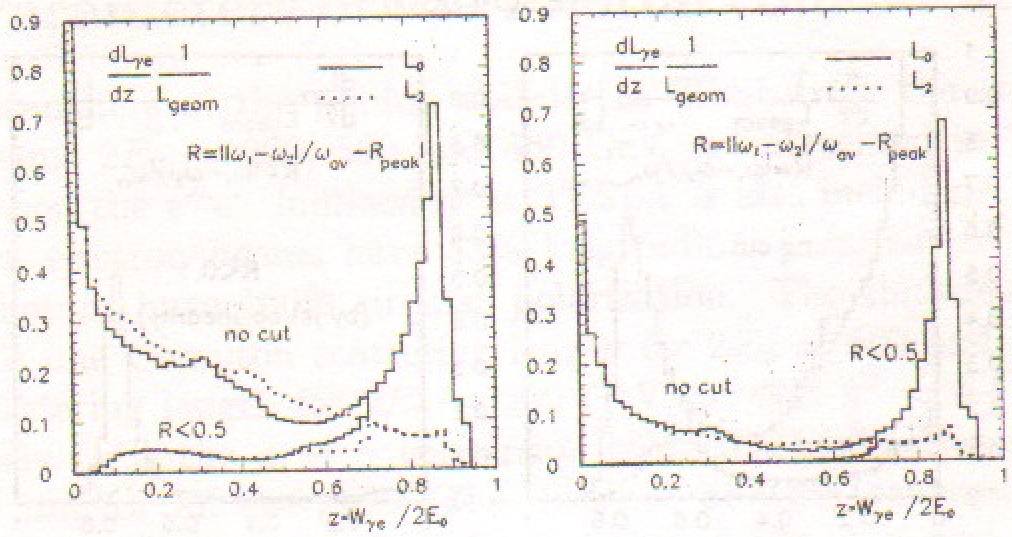

Figure 3: Left: normalized γe luminosity spectra at TESLA(500) when the photon collider is optimized for $\gamma\gamma$ collisions and there is $e \to \gamma$ conversion for both electron beams. Right figure: there is $e \to \gamma$ conversion only for one electron beam and the distance between interaction and conversion point is 1.05cm, 5 times larger than for the left figure.

one can convert only one electron beam, increase the distance between the conversion and the interaction points and obtain the γe luminosity spectrum with suppressed low energy part, Fig. 3-right.

The $\gamma\gamma$ luminosity distributions, including all their polarization characteristics, can be measured using processes $\gamma\gamma \to l^+l^-$ $(l = e, \mu)$. The γe luminosity can be measured using the process $\gamma e^- \to \gamma e^-$ [5].

4 Laser-optics

The photon collider at TESLA requires the laser with wavelength about 1 μm, the flash energy 5 J, duration 1.5 ps and the repetition rate 14 kHz.

All parameters are reasonable for exception of the repetition rate (average power). To overcome this problem each light pulse at TESLA will be used many times. Two schemes are considered. In the first scheme [9, 5], Fig.4, each laser bunch is used for the e→ γ conversion about 12 times. The laser pulse is sent to the interaction region where it is trapped in an optical storage ring. This can be done using Pockels cells (P), thin film polarizers (TFP) and 1/4-wavelength plates ($\lambda/4$). The maximum number of cycles is determined by reflection coefficients of mirrors and attenuation in the Pockels cell.

In the second scheme [11, 9, 12, 5], an "external" optical cavity is used. Using a train of low energy laser pulses one can create in the external cavity

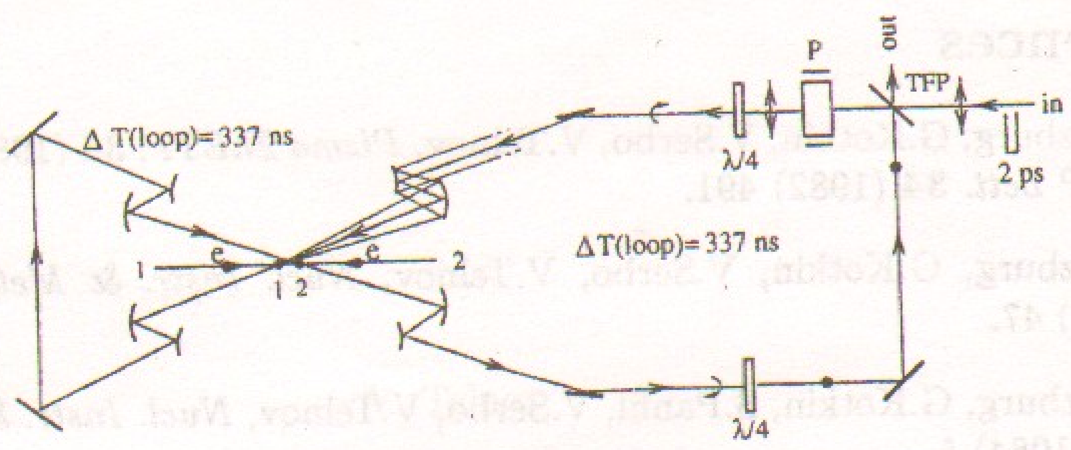

Figure 4: Optical trap (storage ring)

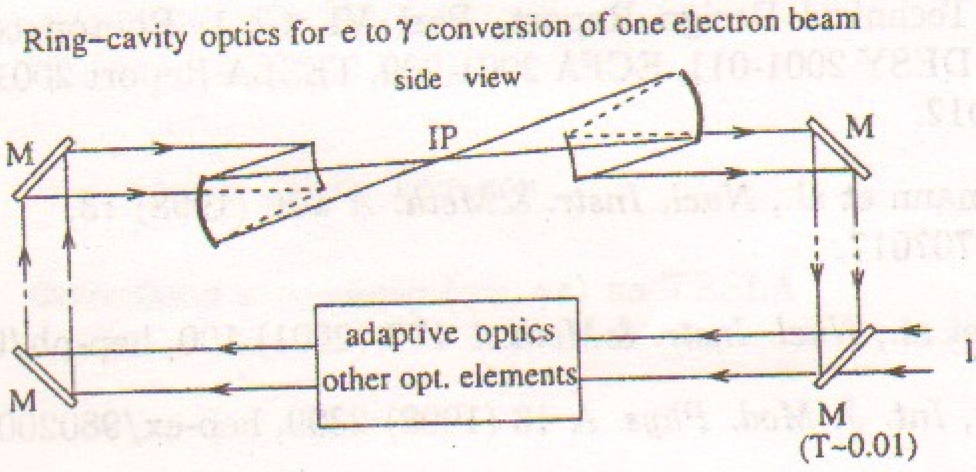

Figure 5: Ring type external optical cavity

(with one mirror having small transmission) an optical pulse with an energy higher than in a laser pulse by a factor Q (cavity quality factor) and this pulse collides with electron bunches many times. As result the required laser power can be lower than in the one-pass case by factor of 50-100.

In the next two-three years a design of the photon collider (interaction region, laser system and specific elements of a detector) should be done. Physics program will be further developed, main processes have to be studied with realistic simulation.

The work has been partially supported by the INTAS 00-00679 grant.

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V. Telnov

Photon Collider ($\gamma\gamma$, γe) at Tesla

В.И. Тельнов

Фотонный коллайдер ($\gamma\gamma$, γe) на TESLA

Ответственный за выпуск А.М. Кудрявцев
Работа поступила 14.11.2001 г.

Сдано в набор 23.11.2001 г.
Подписано в печать 23.11.2001 г.
Формат бумаги 60×90 1/8 Объем 0.7 печ.л., 0.6 уч.-изд.л.
Тираж 105 экз. Бесплатно. Заказ N° 72

Обработано на IBM PC и отпечатано на
ротапринте "ИЯФ им. Г.И. Будкера" СО РАН,
Новосибирск, 630090, пр. академика Лаврентьева, 11.