Charge Asymmetry in $\gamma\gamma \to \mu^+\mu^- + \nu$'s/ $\gamma\gamma \to W^\pm\mu^\mp + \nu$'s, effect of photon non-monochromaticity and $p_\perp$ dependence

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The momentum distributions of positively and negatively charged leptons ($\ell^\pm = \mu^\pm$, $e^\pm$) in the reactions of type $\gamma\gamma \to \ell^+\ell^- + N\nu$, $\gamma\gamma \to W^\pm\ell^\mp + N\nu$ at $\sqrt{s} > 200$ GeV with polarized photons demonstrates a considerable charge asymmetry. We discuss the influence of photon non-monochromaticity on this effect and its dependence on transverse momentum, which will be essential for the study of New Physics effects.

Photon colliders with high energy highly polarized photon beams [1] provide very effective field for the study of new effects of both SM and New Physics. In particularly, it is naturally to expect that the charge asymmetry of leptons, produced in the collision of neutral but highly polarized colliding particles $\gamma\gamma \to \ell^+\ell^- + neutrals$ (where $\ell = \mu$, e), can be a good tool for the discovery of New Physics effects [2].

In this report we study most important background process of this type – the SM process, in which *neutrals* are ν's and main mechanism is given by $\gamma\gamma \to W^+W^-$ process with subsequent lepton decay of W. The latter process (+ other SM processes) will ensure very high event rate at the anticipated luminosity of ILC. The charge asymmetry here appears due to transformation of initial photon helicity into distribution of final leptons via P-violating but CP-preserving leptonic decay of W. Indeed, it was found earlier that the charge asymmetry in distributions of charged leptons in $\gamma\gamma \to \mu^+\mu^-\nu_\mu\bar{\nu_\mu}$ processes is a very strong effect [3]. The same observable final state can be produced in processes with more neutrinos: $\gamma\gamma \to W^\pm\mu^\mp + N\nu$. Contribution of such processes with intermediate τ-lepton was taken into account in [4]. It was shown that this cascade processes changes the asymmetry only weakly. In this report we discuss additionally two new points.

First, the photon beams at the Photon Colliders will be non-monochromatic. How it influence for charge asymmetry?

Second, we present most of results, applying cuts on the muons scattering angles given by $\pi - \theta_0 > \theta > \theta_0$, with $\theta_0 = 10$ mrad, and a cut on muons transverse momentum $p_\perp^c > 10$ GeV, both on each muon or W and on the couple of muons. These simultaneous cuts reduce many backgrounds. We expect that the New Physics effects will be more important at high $p_\perp$. How discussed SM charge asymmetry depend on cut value $p_\perp^c$?

Our numerical results have been obtained with the CompHEP/CalcHEP packages [5], [6] in a version which allows one to take into account the circular polarization of the initial photons and choose different random seed numbers for Monte Carlo (MC) [6].

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$\gamma\gamma \to \mu^+\mu^-\nu\bar{\nu}$, monochromatic photons.

Fig. 1. presents the distributions of muons in the $p_\|$, $p_\perp$ plane, $\partial^2\sigma/(\partial p_\| \partial p_\perp)$ at different photon polarizations for monochromatic beams and without cascade processes.

These figures show explicitly strong difference in the distributions of negative and positive muons as well as strong dependence of distributions on photon polarizations. Therefore, the charge asymmetry in the process is a strong effect.

To obtain quantitative description, we consider normalized mean values of longitudinal $p_\|^\mp$ and transverse $p_\perp^\mp$ momenta of μ^- or μ^+, in the forward hemisphere ($p_\| > 0$, subscript $+$), and take their relative difference as a measure of the longitudinal Δ_L and transverse Δ_T charge asymmetry:

$$P^\pm_{L,T+} = \frac{\int p^\pm_{\|,\perp} d\sigma}{E_\gamma^{max}\int d\sigma}, \quad \Delta_{L,T} = \frac{P^-_{L,T+} - P^+_{L,T+}}{P^-_{L,T+} + P^+_{L,T+}}$$

MC calculations simulate experiment and have statistical uncertainty similar to that in the future experiment. We find it useful to obtain statistical uncertainties $\delta_{L,T}$ of the considered integral characteristics at given expected number of events (about 10^6) by repeating our calculation 5 times with different seed number inputs for MC (with CalcHEP [6]). Also we consider as an independent set of observations data obtained by simultaneous change $\lambda_1,\,\lambda_2 \to -\lambda_1,\,-\lambda_2,\ \mu^- \leftrightarrow \mu^+$ (this change should not change distributions due to CP conservation in SM).

Table I presents obtained average momenta for the positive and negative muons and corresponding asymmetry quantities together with their statistical uncertainties (in percents).

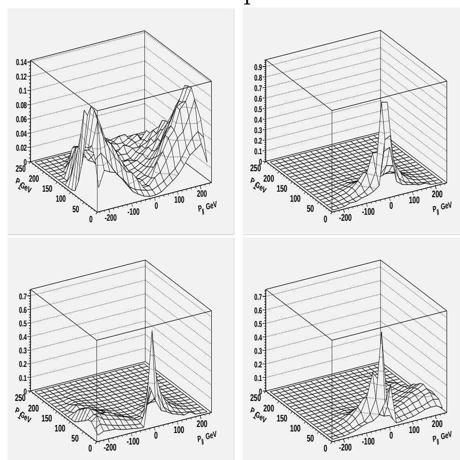

Fig.1 *Muon distribution in* $\gamma_-\gamma_- \to W\mu + \nu's$ *(upper plots) and* $\gamma_+\gamma_- \to W\mu + \nu's$ *(lower plots), left – μ^-, right – μ^+*

$\gamma_{\lambda_1}\gamma_{\lambda_2}$	N	P_N^- δP_N^-	P_N^+ δP_N^+	Δ_N $\delta\Delta_N$
$\gamma_-\gamma_-$	L	0.606 0.29%	0.201 0.55%	0.501 0.57%
	T	0.333 0.61%	0.159 0.28%	0.335 0.44%
$\gamma_+\gamma_-$	L	0.223 0.74%	0.609 0.19%	-0.463 0.47%
	T	0.164 0.08%	0.262 0.31%	-0.231 2.76%

Table I. *Charge asymmetry quantities and statistical uncertainties for* $\gamma_{\lambda_1}\gamma_{\lambda_2} \to W\mu\nu$ *process, N=T or L.*

Cascade process contribution.

The final state $\mu\mu$ (or $W\mu$) + *missing* $p_\perp$ mainly arises through the process $\gamma\gamma \to \mu^+\mu^-\nu_\mu\bar{\nu}_\mu$ ($\gamma\gamma \to W\mu\nu$). In addition, *cascade processes* such as $\gamma\gamma \to \tau^+\mu^-\nu_\tau\bar{\nu}_\mu$ ($\gamma\gamma \to W\tau\nu$), $\tau \to \mu\nu_\mu\nu_\tau$, contribute at the level 37% (17%) relative to the leading contribution. The straightforward calculation of such processes is out of potential of known packages. The good way give here *double-resonant (DRD) approximation*, in which one consider only diagrams $\gamma\gamma \to W^+W^-$ (DRD diagrams) with subsequent decay of W to leptons. Direct calculation shows these DRD-diagrams are responsible for about 98% of the total $\gamma\gamma \to W\mu\nu$ cross-section. The same is valid for the momentum distributions. Therefore the inaccuracy implemented by the using of DRD approximation for cascade process is no more than $2\% \cdot Br(\tau \to \mu) \approx 0.3\%$. That is within statistical uncertainty shown in the Table I.

In the framework of DRD approximation, the polarization of τ in the rest frame of W is collinear with the known momentum of corresponding neutrino, and the momentum distribution of muons from the decay of τ in this system is calculated easily. The distribution of final muons in our process is given by the convolution of the mentioned accurate distribution of μ in τ decay with the CompHEP-generated distribution [4].

Note that the decay $\tau \to \mu\nu_\tau\nu_\mu$ involves three particles. The effective mass of the neutrino pair $m_{\nu\nu}$ varies from 0 to almost m_τ. Hence, in the collision frame $E_\mu \leq E_\tau(1 - m_{\nu\nu}^2/m_\tau^2)$. Therefore, the distribution of muons in the cascade process is similar in the main features to that of incident τ, but it is strongly contracted to the origin of coordinates. Therefore, cascade processes change the asymmetry only weakly, and their contribution to the asymmetry reduces even more with the growth of applied cuts (see [4]).

Effect of photon non-monochromaticity

At the Photon Collider photons will be non-monochromatic with spectra peaked near the high energy limit E_γ^{max}. Moreover, due to the finite distance between conversion point (CP) and interaction point (IP) and also due to rescatterings of laser photons on electrons after first collision with laser photon, photon spectra even non-factorizable. Fortunately in the high energy part of spectra ($E_\gamma > E_\gamma^{max}/\sqrt{2}$) these spectra are factorizable with high precision and these photons have high degree of polarization. Moreover, the form of effective spectra in this region is described with high accuracy with the aid of one additional parameter only, independent on details of organization of experimental set up [7]. The luminosity of Photon Collider is normalized for this very region only.

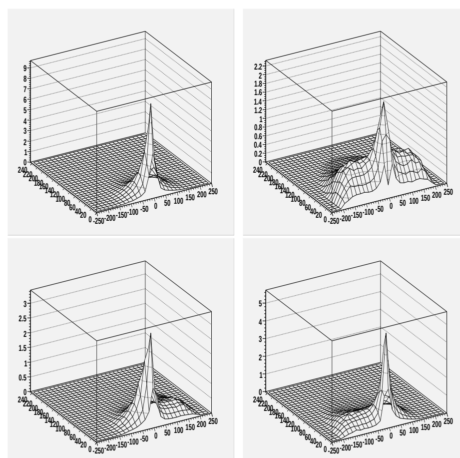

Fig.2 *The distributions of muons calculated with "realistic" spectra distribution. Upper plots - $\gamma_-\gamma_-$. Lower plots – $\gamma_+\gamma_-$. Left – μ^-, right – μ^+*

As for low energetic tail of effective photon spectrum it depends strongly on details of experimental set-up which will vary in the process of construction of ILC.

So, in our simulations for the high energy part of the spectrum $E_\gamma > E_\gamma^{max}/\sqrt{2}$ we used the approximation from [7] with $\rho = 1$ and $x = 4.8$ with polarization for ideal Compton effect [1]. To imitate low energy part of spectrum we used spectra from [1] for the case when IP and CP coincide ($\rho = 0$) and consider these photons to be unpolarized. The resulting distributions of muons are presented on Fig. 2. These distributions resemble the distributions presented on Fig. 1. with additional wide peak at low energies. Table II shows the corresponding asymmetry quantities. These values are slightly smaller in comparison to monochromatic case. But they are still large enough and replicate in main features the values in Table I (with approximately the same statistical uncertainties).

$\gamma_{\lambda_1}\gamma_{\lambda_2}$	N	P_N^-	P_N^+	Δ_N
$\gamma_-\gamma_-$	L	0.365	0.157	0.398
	T	0.284	0.179	0.228
$\gamma_+\gamma_-$	L	0.174	0.338	-0.321
	T	0.200	0.236	-0.082

Table II. *Charge asymmetry quantities for "realistic" photon spectra.*

Dependence on $p^c_{\perp\mu}$ cut

New Physics effects are expected to be switched on at the relatively large transverse momenta. That is why we study the dependence of observed effects on the cut value $p^c_{\perp\mu}$.

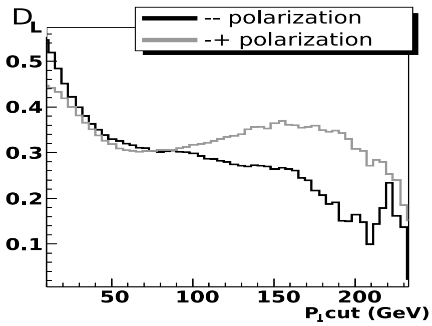

Fig.3 *The $p^c_{\perp\mu}$ dependence of asymmetry.*

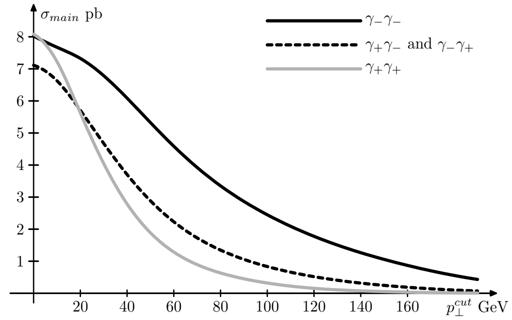

Fig.4 *The smoothed $\gamma\gamma \to W^+\mu^-\bar{\nu}$ cross section dependence on $p^c_{\perp\mu}$.*

Figs. 3 and 4 show the $p^c_{\perp\mu}$ dependence of the asymmetry quantity Δ_L and the cross section of the $\gamma\gamma \to W^+\mu^-\bar{\nu}$ process. One can see that the asymmetry remains large even with large cuts, while the cross section quickly reduces.

Conclusions.

- The asymmetry effect is huge and easily observable.
- Cascade process weakly affect the asymmetry.
- Introduced quantities (especially Δ_L) are large even with large $p^c_{\perp\mu}$ cuts (but the number of events reduces strong at large $p^c_{\perp\mu}$).
- Taking into account same effects for $e^+ e^-$, $e^+ \mu^-$, $\mu^+ e^-$ enhance effective cross section for $\gamma\gamma \to \ell^+\ell^-\nu\bar{\nu}$ from 1.2 to 4.8 pb and for $\gamma\gamma \to W^+\ell^-\bar{\nu}$, etc. to 30 pb.
- The statistical uncertainty is at the level of radiative corrections, so the tree-level approximation is sufficient
- Non-monochromaticity of photon spectra decreases the considered asymmetries but retain them large enough.

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