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CHARGE ASYMMETRIES IN $\gamma\gamma \to \mu^+\mu^- + \nu$'s/ $\gamma\gamma \to W^\pm\mu^\mp + \nu$'s WITH POLARIZED PHOTONS CASCADE $\tau \to \mu\mu\bar{\nu}$ CONTRIBUTION *

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It is shown that the difference in the momentum distributions of positively (μ^+, e^+) and negatively (μ^-, e^-) charged leptons in the reactions of type $\gamma\gamma \to \mu^+\mu^- + N\nu$, $\gamma\gamma \to W^\pm\mu^\mp + N\nu$ at $\sqrt{s} > 200$ GeV with polarized photons demonstrates a considerable *charge asymmetry* of muon distributions, sensitive to New Physics effects. Contribution of processes with intermediate τ-lepton in $\gamma\gamma \to W^\pm\mu^\mp + N\nu$ is taken into account.

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The Standard Model (SM) cross section of $\gamma\gamma \to W^+W^-$ at energies larger than 200 GeV is about 80 pb. Thanks to the planned high luminosity of the Photon Collider (PC) at the International Linear Collider ILC [1,2], it will ensure very high event rate.

It was shown in Ref. [3] that the charge asymmetry in the distributions of charged leptons in $\gamma\gamma \to \mu^+\mu^-\nu_\mu\bar{\nu}_\mu$ ($\gamma\gamma \to W^\pm\mu^\mp\nu_\mu$) processes with polarized photons is a very strong effect, and that it is sensitive to some possible effects of New Physics. The final state $\mu\mu$ ($W + \mu$ + *missing* $p_\perp$) mainly appears via 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. In this paper we improve the results of Ref. [3] with the account of the effects of the cascade process.

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1. DRD approximation

Among the 5 types of tree-level diagrams contributing to the process $\gamma\gamma \to \mu^+\mu^-\nu\bar{\nu}$, double-resonant diagrams (DRD) provide the largest contribution. In these diagrams, leptons are produced from an intermediate W^+W^--pair. Numerical estimates suggest that non-DRD diagrams may contribute to the cross-section at the level of about 5%. However, they interfere destructively, and finally DRD diagrams are responsible for about 98% of the total $\gamma\gamma \to W\mu\nu$ cross-section. Based on these results, we can describe cascade processes within the DRD approximation, *i.e.* considering only DRD diagrams. We also checked that the DRD approximation describes well the properties of the charge asymmetry.

2. Numerical results

Numerical results have been obtained with the CompHEP/CalcHEP packages [4, 5] in a version which allows one to take into account the circular polarization of the initial photons and choose different random seed numbers for the Monte Carlo (MC) phase space integration and event generation [5]. To reduce the background we applied simultaneous cuts on the muon's scattering angles, $\pi - \theta_0 > \theta > \theta_0$, 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.

We consider normalized mean values of longitudinal $p_\parallel^\mp$ and transverse $p_\perp^\mp$ momenta of μ^- or μ^+, in the forward hemisphere ($p_\parallel > 0$, subscript $+$), and take their relative difference as a measure of the longitudinal $\Delta_{\rm L}$ and transverse $\Delta_{\rm T}$ charge asymmetry:

$$P^\pm_{\rm L,T+} = \frac{\int p^\pm_{\parallel,\perp} d\sigma}{E_{\gamma\max}\int d\sigma}, \qquad \Delta_{\rm L,T} = \frac{P^-_{\rm L,T+} - P^+_{\rm L,T+}}{P^-_{\rm L,T+} + P^+_{\rm L,T+}}\,. \tag{1}$$

The integral characteristics in Eq. (1) have statistical uncertainties, $\delta_{\rm L,T}$, (similar to those in the future experiment) due to the MC nature of the events generation. We evaluate them at a given expected number of generated events (about 10^6) by repeating the calculation 5 times with different seed number inputs for MC (with CalcHEP [5]). We also consider, as an independent set of observations, events obtained by simultaneous change λ_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 relative statistical uncertainties. Everywhere under the value of each considered quantity we present its relative statistical uncertainty.

TABLE I

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

$\gamma_{\lambda_1}\gamma_{\lambda_2}$	N	P_N^- δP_N^-	P_N^+ δP_N^+	Δ_N $\delta\Delta_N$
$\gamma_-\gamma_-$	L	0.599 0.35%	0.170 0.37%	0.557 0.37%
	T	0.338 0.96%	0.150 0.42%	0.386 0.99%
$\gamma_+\gamma_-$	L	0.209 0.82%	0.556 0.34%	-0.454 0.52%
	T	0.159 0.72%	0.249 0.82%	-0.220 2.52%

We have checked that the quantities $\Delta_{\mathrm{L,T}}$ change their sign with the change of sign of both photon helicities (within the statistical uncertainty) as it should be in SM.

3. Cascade process contribution

In the framework of DRD approximation, the polarization of the τ in the rest frame of W is determined by the SM vertex factor, $\tau^+ W_\mu^- \gamma^\mu (1-\gamma^5)\nu_\tau$ + h.c. Due to the $\gamma^\mu(1-\gamma^5)$ factor, the τ helicity coincides with that of the ν_τ, it is positive for τ^+ and negative for τ^- (with accuracy to m_τ/M_W) and independent of W polarization. The spin vector of the τ is expressed easily via momenta of τ and ν_τ, p and p_ν, respectively, as $\pm s/2$, ($+$ for τ^+, $-$ for τ^-), where

$$s = \frac{(p_\nu m_\tau/(pp_\nu) - p/m_\tau)}{\sqrt{2}} \,. \tag{2}$$

Denoting the momentum of the μ by k, the distribution of muons in τ-decay with momentum p and spin $\pm s$ can be written neglecting muon mass as

$$f = 4\left[(3m_\tau^2 - 4pk)pk + ks\, m_\tau(4pk - m_\tau^2)\right] d\Gamma/\left(\pi E_\tau m_\tau^4\right)\,, \tag{3}$$

where $d\Gamma$ is a phase space element boosted to the lab frame. In the τ rest frame $d\Gamma = \theta\,(m_\tau/2 - k)\, d^3k/E_\mu$. The distribution of final muons from the τ cascade is obtained by convolution of the distribution of τ-leptons, calculated precisely in tree approximation by CompHEP/CalcHEP, with the boosted distribution in Eq. (3). The effective mass of the neutrino pair $m_{\nu\nu}$ in the decay $\tau \to \mu\nu_\tau\nu_\mu$, 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 the muons in the cascade process is similar in the main features to that of the incident τ, but it is strongly contracted to the origin of coordinates.

Fig. 1 shows the total observable distributions of muons — the sum of distributions of the muons in $\gamma\gamma \to W\mu\nu$ and $\gamma\gamma \to W\tau\nu \to W\mu\nu\nu\nu$. The distributions of the muons in $\gamma\gamma \to W\mu\nu$ presented in Ref. [3] differ from these complete distributions practically only at small momenta.

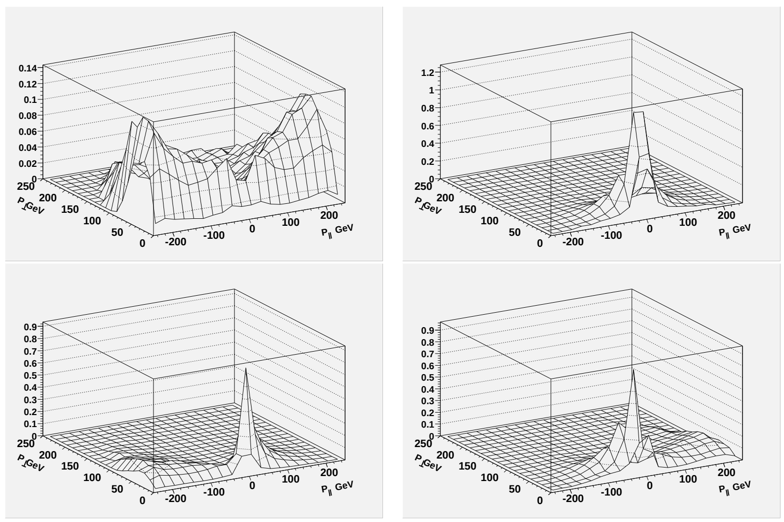

Fig. 1. Total muon distribution in $\gamma_-\gamma_- \to W\mu + \nu's$ (upper plots) and $\gamma_+\gamma_- \to W\mu + \nu's$ (lower plots), left — μ^-, right — μ^+.

TABLE II

Resulting asymmetry quantities.

$\gamma_{\lambda_1}\gamma_{\lambda_2}$	N	P_N^-	P_N^+	Δ_N
$\gamma_-\gamma_-$	L	0.548	0.164	0.539
	T	0.311	0.142	0.374
$\gamma_+\gamma_-$	L	0.199	0.513	-0.440
	T	0.152	0.232	-0.207

Table II presents the corresponding total asymmetry quantities. The comparison with Table I shows that the asymmetry parameters $\Delta_{\mathrm{L,T}}$ decrease due to the cascade process in average by about 3% only.

Since $\gamma\gamma \to W\tau\nu \to W\mu\nu\nu\nu$ distributions are concentrated at small $(p_\parallel, p_\perp)$, the applied cuts reduce their contribution much stronger than the main contribution. They also reduce the inaccuracy in the final asymmetry introduced by DRD approximation.

4. 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 the charge asymmetries on the cut $p^c_{\perp\mu}$. Fig. 2 shows the dependence of the asymmetries $\Delta_\perp$ and $\Delta_\parallel$ on $p^c_{\perp\mu}$. The longitudinal charge asymmetry remains large even with large cuts while the transverse charge asymmetry diminishes increasing the $p^c_{\perp\mu}$. In particular, for "$+-$" polarization at $p^c_{\perp\tau} \geq 120$ GeV quantities $P^+_{\rm T}$ and $P^-_{\rm T}$ coincide giving practically negligible $\Delta_{\rm T}$ — see Fig. 2, with naturally high statistical uncertainty in this quantity — see Table III below.

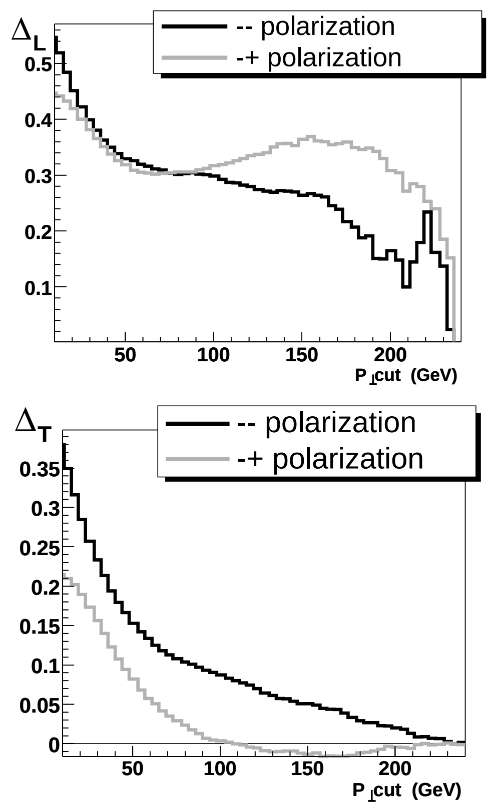

Fig. 2. The $p^c_{\perp\mu}$ dependence of asymmetry. Top plot – $\Delta_{\rm L}$, bottom plot — $\Delta_{\rm T}$.

The total cross section decreases at larger values of $p^c_{\perp\mu}$, but the relative value of the contribution of the cascade process decreases much faster than that of the total cross section (Fig. 3). This is caused by the above mentioned contraction of the available phase space for the muons obtained from the τ decay.

TABLE III

Inaccuracy of DRD approximation for $\Delta_{\mathrm{L,T}}$ at different $p^c_{\perp\tau}$ for τ-channel.

$\gamma_{\lambda_1}\gamma_{\lambda_2}$N	P^-_{N+}	P^+_{N+}	Δ_N
$\gamma_-\gamma_-$ N=L	0.519	0.287	0.289
N=T	r 0.385	0.236	0.240
$\gamma_+\gamma_-$ N=L	0.325	0.569	−0.271
N=T	0.222	0.310	-0.201
$\gamma_-\gamma_+$ N=L	0.295	0.545	−0.250
N=T	0.216	0.308	−0.175

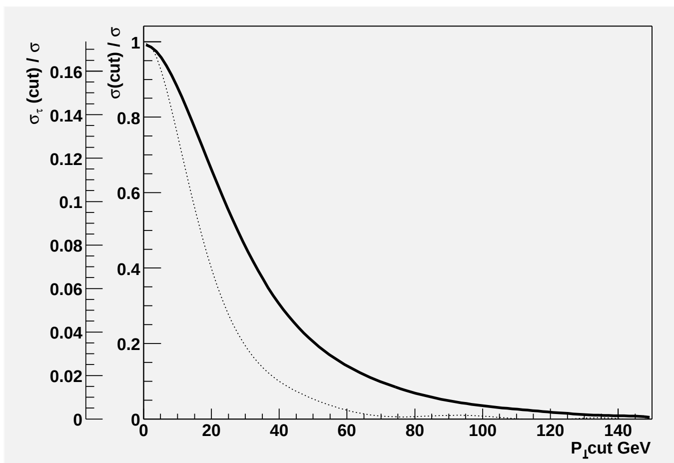

Fig. 3. The $p^c_{\perp\mu}$ dependence of cross section, $\sigma^{\mathrm{trunc}}_{\mathrm{tot}}$. Full line, right scale — fraction of $\sigma^{\mathrm{trunc}}_{\mathrm{tot}}/\sigma_{\mathrm{tot}}$, dotted line, left scale — fraction of cascade process in $\sigma^{\mathrm{trunc}}_{\mathrm{tot}}$.

• **To estimate the inaccuracy** implemented by the DRD approximation we generate first events by applying a cut on the transverse momentum of τ $p_{\perp\tau} \geq p^c_{\perp\tau}$. The quantity of interest is given by $\delta_{\mathrm{approx}}(p^c_{\perp\tau}) = \delta\sigma_\tau(p^c_{\perp\tau}) \times \delta_{\mathrm{DRD}}(p^c_{\perp\tau})$. Here $\delta\sigma_\tau$ is the fraction of the total cross section given by the cascade process, and δ_{DRD} is the inaccuracy of the DRD approximation for the asymmetry parameters $\Delta_{\mathrm{L,T}}$ in Eq.(1).

We determine this inaccuracy by comparing the exact calculation for the process $\gamma\gamma \to W\tau\nu$ with that obtained in the DRD approximation. These inaccuracies for different values of $p^c_{\perp\tau}$ are presented in Table III.

Finally, the inaccuracy of approximation $\delta_{\mathrm{approx}}(p^c_{\perp\tau})$ decreases when increasing $p^c_{\perp\tau}$. Indeed, the 1-st factor in our estimate for $\delta_{\mathrm{approx}}(p^c_{\perp\tau})$ decreases very quickly while the 2-nd factor increases only weakly.

5. Summary

The effects studied here are identical for electrons and muons. Thus, in the complete analysis contributions of all $e^+ e^-$, $e^+ \mu^-$, $\mu^+ e^-$ distributions must be taken into account. This will enhance the value of the cross section for $\gamma\gamma \to \mu^+\mu^-\nu\bar{\nu}$ from 1.2 to 4.8 pb and for $\gamma\gamma \to W^+\mu^-\bar{\nu}$, *etc.* to 30 pb.

• The statistical uncertainty is at the level of the radiative corrections, so the tree-level approximation is sufficient for the description of the future experiments.

• Real photon bunches at the Photon Collider will not be monochromatic [2]. However, as shown in Ref. [3], this non-monochromaticity decreases only slightly the value of the asymmetries considered here.

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