New observables in high energy photon collisions

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Outline

The ILC has the very interesting option of providing us with a Photon Collider (very high energy polarized photon beams [compton back-scattering]

The Standard Model (SM) cross section of $\gamma\gamma \to W^+W^-$ at center of mass energy greater than 200 GeV remains constant of about 80 pb up to higher energies and practically independent on photon polarization.

At $\sqrt{s} > 200$ GeV this cross section is more than 10 times larger than the cross section of W production in e^+e^- mode, $\sigma_{e^+e^- \to W^+W^-}$. It will ensure very high event rate at the anticipated luminosity .

The distributions of W^+ and W^- in $\gamma\gamma \to W^+W^-$ are charge symmetrical, their polarizations are determined by the polarization of initial photons.
The distribution of muons in subsequent decay of polarized $W^\pm \to \mu^\pm\nu$ is asymmetrical [*due to P violation in the SM*].

Charge asymmetries appear in processes like

$$\gamma\gamma \to \mu^+\mu^-\nu_\mu\bar{\nu}_\mu, \quad \gamma\gamma \to W^\pm\mu^\mp\nu$$

and are due to P nonconservation in the SM.

We also consider cascade processes like:

$$\gamma\gamma \to \tau\mu\nu\nu \ (\gamma\gamma \to W\tau\nu) \quad \to \quad \mu^+\mu^-\nu\nu\nu\nu \ (W\mu\nu\nu\nu)$$

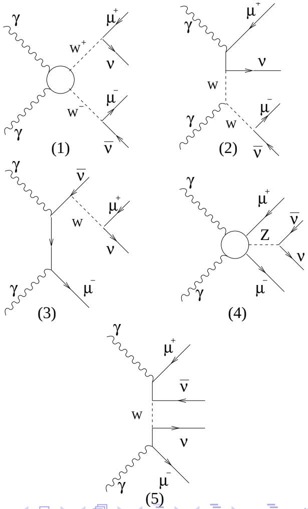
(with $\tau \to \mu\nu_\mu\nu_\tau$ decay) produce the same observable final state enhancing total event rate by 37%(17%).

Photon spectra are non-monochromatic. Photons with energy $E_\gamma < E_\gamma^{max}/\sqrt{2}$ are non-polarized. How this fact reduce asymmetry?

DIAGRAMS FOR $\gamma\gamma \rightarrow \mu^+\mu^-\nu_\mu\bar{\nu}_\mu$ $(\gamma\gamma \rightarrow W\mu\nu\nu)$

(1) 3 double-resonant diagrams (DRD)
(2) 4 single-resonant diagrams (SRD_W)
(3) 4 single resonant diagrams (SRD_μ
(4) 6 diagrams with Z radiation
(5) 2 multi-peripheral non-resonant diagrams

SRD (2)/DRD (1) is about 5%.
The interference SRD, DRD is destructive.
[(3)+(4)+(5)]/[DRD (1)] $\ll$ 1.
DRD contribution covers almost 98.7 % cross section.
(The $\gamma\gamma \rightarrow W^+\mu^-\bar{\nu}$ is described by only first 3 groups.)



We used CalcHEP for calculations.

For each observed particle:

Cut in escape angle θ

$$\pi - \theta_0 > \theta > \theta_0 \quad \text{with} \quad \theta_0 = 10\, mrad,$$

Cut in transverse momentum $p_\perp$:

$$p_\perp > p^c_{\perp\mu} \qquad \text{with} \qquad p^c_{\perp\mu} = 10 \text{ GeV}$$

(with higher $p^c_{\perp\mu}$ up to 140 GeV).

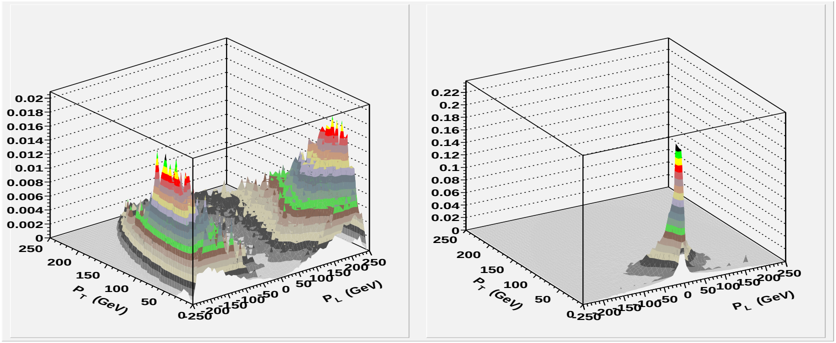
These simultaneous cuts allow many backgrounds to be eliminated.

The number of generated events = anticipated annual number $\simeq 10^6$ events,
This, in the non-monochromatic case, is the # of events generated by photons with $E_\gamma > E_\gamma^{max}/\sqrt{2}$.

Outline

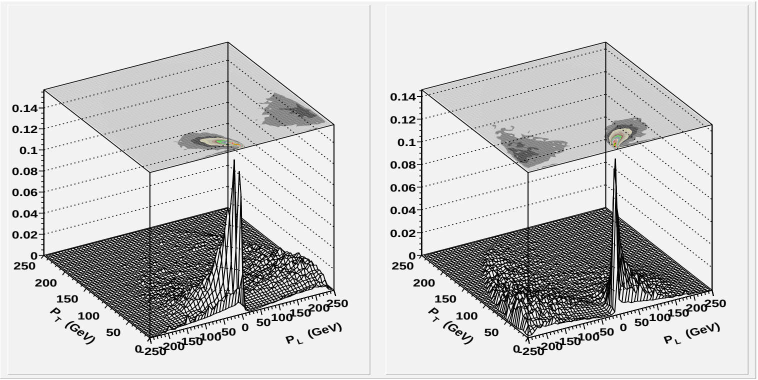
Difference between distributions of positive and negative muons in $\gamma_{\lambda_1}\gamma_{\lambda_2} \to W\mu\nu$ (no cuts)

Both photons are left polarized, $\gamma_-\gamma_-$



Negative μ distribution. Positive μ distribution.

First photon is left polarized, second is right polarized, $\gamma_-\gamma_+$



Negative μ distribution. Positive μ distribution.

Note: the distributions are mirror-symmetric.

For $\gamma\gamma \to W^{\pm}\mu^{\pm} + \nu$'s processes we considered normalized mean values of longitudinal $p_{\parallel}^{\mp}$ and transverse $p_{\perp}^{\mp}$ momenta of muons:

$$P_L^{\pm} = \frac{\int p_{\parallel}^{\pm} d\sigma}{E_{\gamma}^{max} \int d\sigma}, \quad P_T^{\pm} = \frac{\int p_{\perp}^{\pm} d\sigma}{E_{\gamma}^{max} \int d\sigma},$$

and taken their relative difference as a measure of charge asymmetry:

$$\Delta_L = \frac{P_L^- - P_L^+}{P_L^- + P_L^+}, \quad \Delta_T = \frac{P_T^- - P_T^+}{P_T^- + P_T^+}.$$

- Quantities for $\gamma_+\gamma_+$ and $\gamma_-\gamma_+$ can be obtained with $\mu^+ \leftrightarrow \mu^-$ exchange for P_N and with sign change for Δ_N.

- Experimental uncertainty (δexp) is expected to be $\gtrapprox \delta_{MC}$ the statistical uncertainty of Monte Carlo simulations (Comphep).

$\gamma_{\lambda_1}\gamma_{\lambda_2}$	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 0.82%	0.609 0.19%	-0.463 0.47%
	T	0.164 0.08%	0.262 0.31%	-0.231 0.76%

Charge asymmetry quantities and statistical uncertainties for $\gamma_{\lambda_1}\gamma_{\lambda_2} \rightarrow W\mu\nu$. Monochromatic case.

$\sqrt{s_{\gamma\gamma}} = 500$ GeV

Our numbers $\delta P_{L,T}, \delta\Delta_{L,T}$ will thus provide a lower bound to to the experimental uncertainty $(\delta P_{L,T})_{exp}$, $(\delta\Delta_{L,T})_{exp}$.

Outline

Cascade process

Muons with missing transverse momentum can appear via processes

$$\gamma\gamma \to \tau^+\mu^-\nu_\tau\bar{\nu}_\mu \; (\gamma\gamma \to W\tau\nu)$$

followed by $\tau \to \mu\nu_\mu\nu_\tau$.

Total event rate enhancement

- for $\gamma\gamma \to W\mu + \nu's$: $B \equiv Br(\tau \to \mu\nu\nu) = 17\,\%$
- for $\gamma\gamma \to \mu^+\mu^- + \nu's$: $2B + B^2 \approx 37\,\%$.

Calculation of such processes (6 or more final particles) is a computationally challenging task.
Reasonable (DRD) approximations provides high enough accuracy for our purposes.

In the frame of DRD each τ is produced from W decay $\Rightarrow$ τ polarisation is known and we are allowed to *convolute* generated distribution of τ in $\gamma\gamma \to W\tau\nu$ with distribution of μ in τ decay:

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

Here k and p are 4-momenta of μ and τ.

Spin of τ: $\pm s/2$, $s = \frac{1}{\sqrt{2}}\left(\frac{p_\nu m_\tau}{(pp_\nu)} - \frac{p}{m_\tau}\right)\begin{cases} + & \text{for } \tau^+, \\ - & \text{for } \tau^-. \end{cases}$

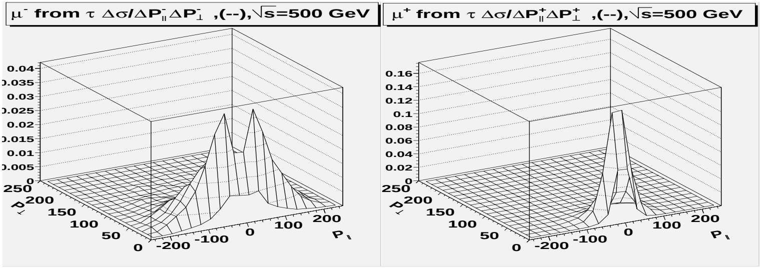
Essential Feature

Decay $\tau \to \mu\nu_\tau\nu_\mu$ involves 3 particles, the effective mass of the $\nu\bar{\nu}$ system $m_{\nu\nu}$ varies from 0 to m_τ

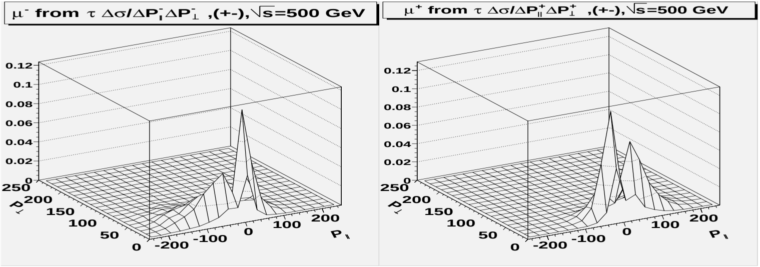
$\Rightarrow$ the μ distribution is *contracted* in comparison with τ distribution:

$$E_\mu \le E_\tau(1 - m_{\nu\nu}^2/m_\tau^2).$$

Distributions of μ in cascade process

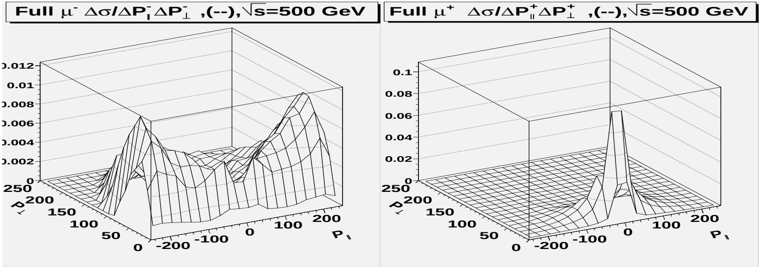


Muon distribution in $\gamma_-\gamma_- \to W\mu\nu\nu\nu$

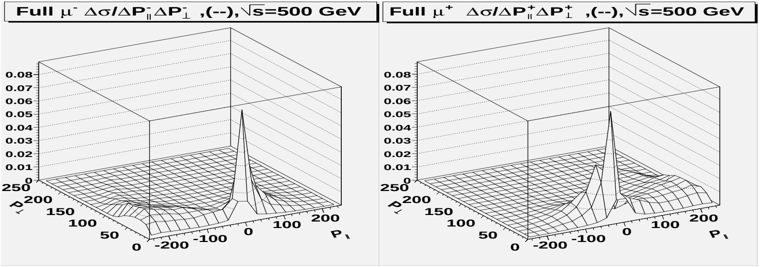


Muon distribution in $\gamma_+\gamma_- \to W\mu\nu\nu\nu$ left $-\mu^-$,right $-\mu^+$

Full (DRD+cascade) distributions of μ

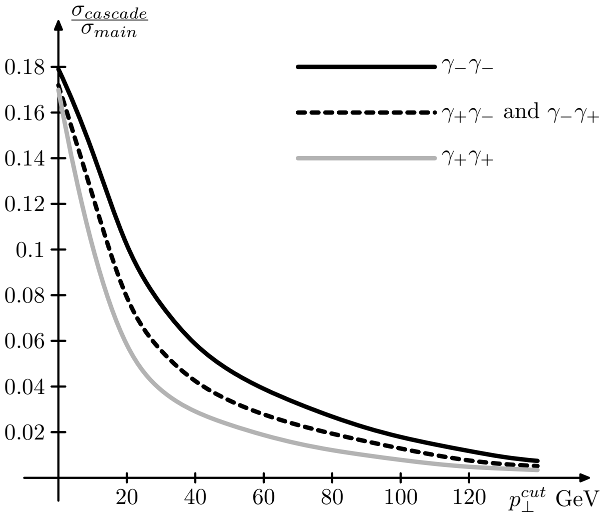


Total muon distribution in $\gamma_-\gamma_- \rightarrow W\mu + \nu's$



Total muon distribution in $\gamma_+\gamma_- \rightarrow W\mu + \nu's$ left $-\mu^-$,right $-\mu^+$

Contribution of cascade process relative to the cross-section of the main process.



Outline

• Cascade process changes μ distribution only at small momenta.

• Asymmetry parameters decrease by $\lesssim 3\%$

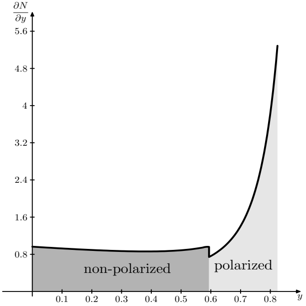
$\gamma_{\lambda_1}\gamma_{\lambda_2}$	N	P_N^-	P_N^+	Δ_N
$\gamma_-\gamma_-$	L	0.548	0.164	0.539
	T	0.311	0.142	0.374
$\gamma_+\gamma_-$	L	0.199	0.513	-0.440
	T	0.152	0.232	-0.207

Total charge asymmetry quantities.

• Applied cuts reduce the contribution of cascade process more than the main contribution $\Rightarrow$ *reduce* inaccuracy of DRD approximation in the description of charge asymmetry at increasing values of $p^c_{\perp\mu}$.

Photon spectra

High energy part $E_\gamma > E_\gamma^{max}/\sqrt{2}$ is obtained from ideal one (*Compton spectrum*) with known factor dependent on photon energy and distance conversion point – collision point. The polarization distribution on energy is the same as in the ideal case (Ginzburg, Kotkin). At lower energies factorization is broken, polarization disappears. Details depend strongly on real collision scheme.



To take into account this behavior, we used factorized spectra,
for $E_\gamma > E_\gamma^{max}/\sqrt{2}$ (Ginzburg, Kotkin),
for $E_\gamma < E_\gamma^{max}/\sqrt{2}$ – ideal Compton spectrum without geometrical factors, no polarization.
Luminosity was normalized for product of high energy photon fluxes.

$\gamma_{\lambda_1}\gamma_{\lambda_2}$	N	P_N^- / δP_N^-	P_N^+ / δP_N^+	Δ_N / $\delta\Delta_N$
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Monochromatic case

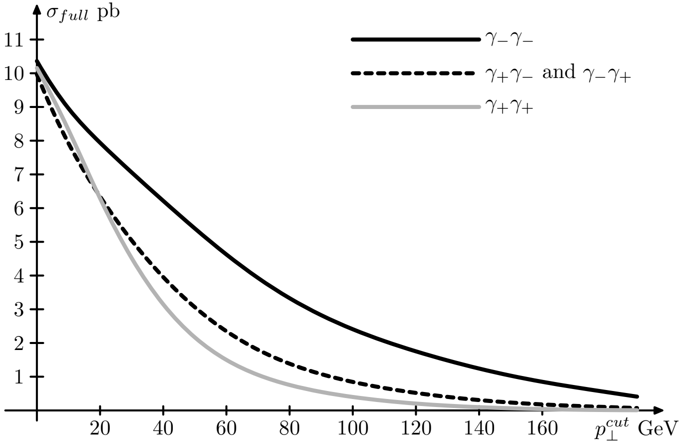
P_N^- / δP_N^-	P_N^+ / δP_N^+	Δ_N / $\delta\Delta_N$
0.365 0.31%	0.157 0.22%	0.398 0.18%
0.284 0.38%	0.179 0.11%	0.228 0.81%
0.174 0.24%	0.338 0.28%	-0.321 0.43%
0.200 0.09%	0.236 0.16%	-0.082 0.42%

Non-monochromatic case

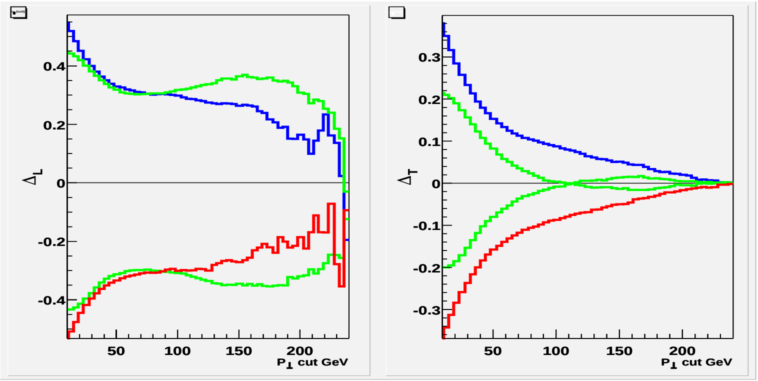
Charge asymmetry quantities and their uncertainties for $\gamma_{\lambda_1}\gamma_{\lambda_2} \to W\mu\nu$, $p^c_{\perp\mu} = 10$ GeV.

In the non-monochromatic case charge asymmetry quantities are reduced typically by a factor 1.3-1.5, their computed uncertainties do not change very much.

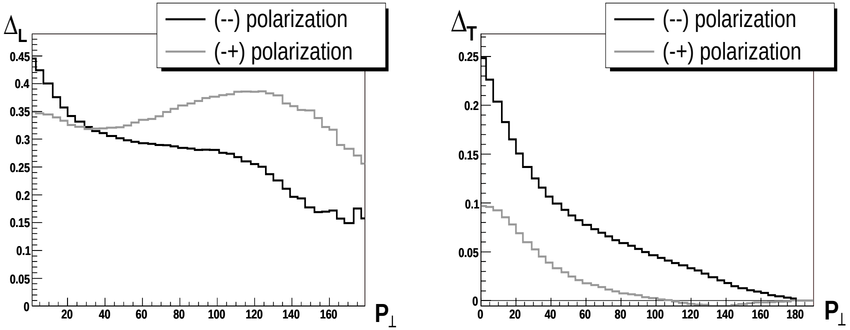
The $p^c_{\perp\mu}$ dependence of resulting cross sections for different photon polarizations:



New Physics is expected to be switched on at large transverse momenta. We study the dependence of asymmetry on the cut $p^c_{\perp\mu}$.



The $p^c_{\perp\mu}$ dependence of asymmetry. Left – Δ_L, right – Δ_T,
blue – $\gamma_-\gamma_-$, green – $\gamma_-\gamma_+$ and $\gamma_+\gamma_-$, red – $\gamma_+\gamma_+$



The asymmetry Δ_L does not decrease appreciably with increasing values of the momentum cut $p^c_{\perp\mu}$.

The asymmetry Δ_T instead decreases faster.

Outline

Conclusions and Outlook

- Charge Asymmetries are large and easily measurable.
- Cascade process weakly affects the asymmetry.
- The introduced quantities (especially Δ_L) are large even with large $p^c_{\perp\mu}$ cuts.
- Taking into accont the same effects for $e^+ e^-$, $e^+ \mu^-$, $\mu^+ e^-$ enhances the statistics by 4 times (it is taken into account).
- The non-monochromaticity of photon spectra decreases the charge asymmetries but leaves them large enough.

We plan to use the charge asymmetries in the study of New Physics effects (e.g. MSSM). We hope that they will help!!