Polarization at Photon colliders. Example

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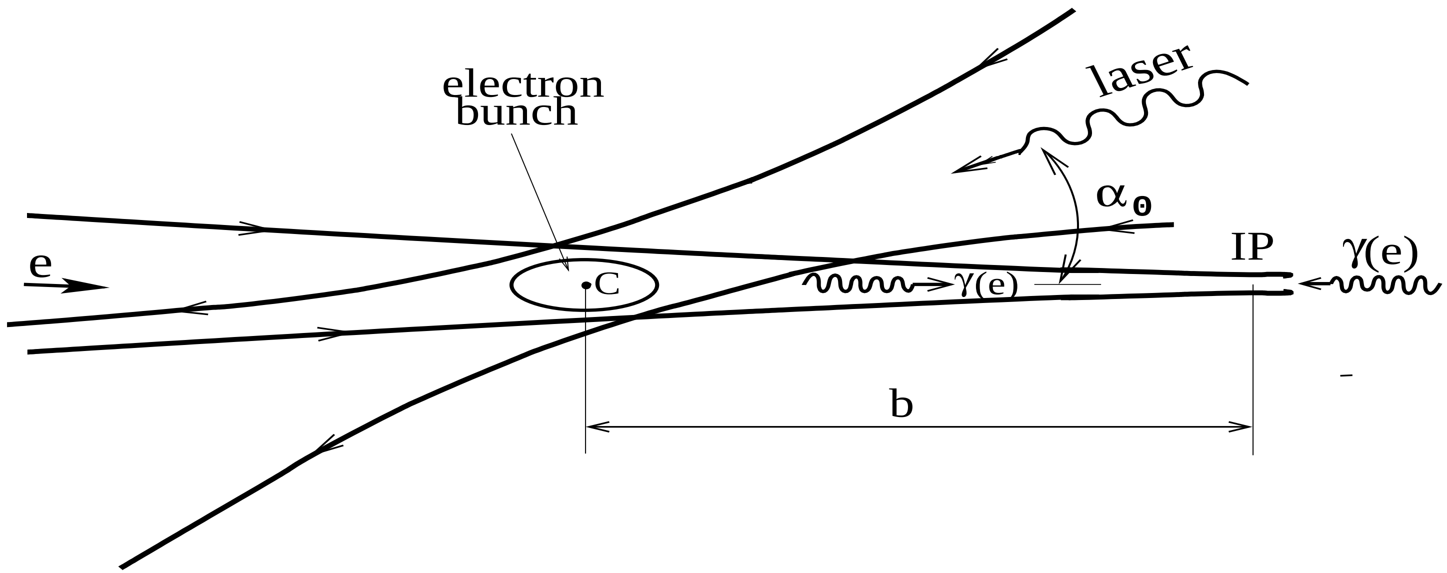
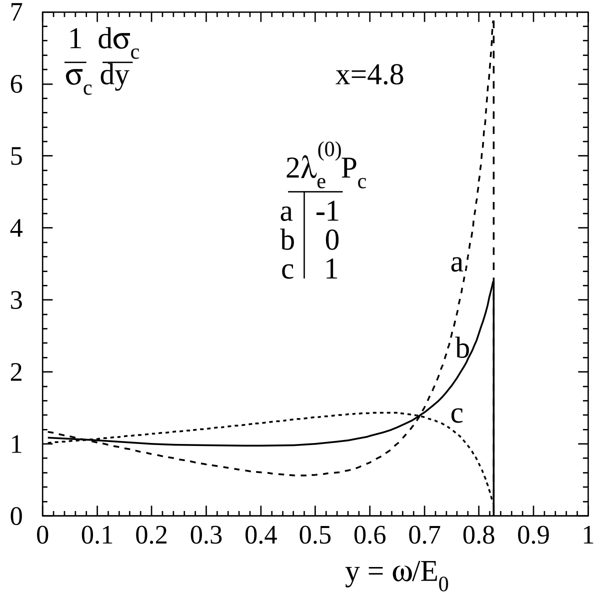
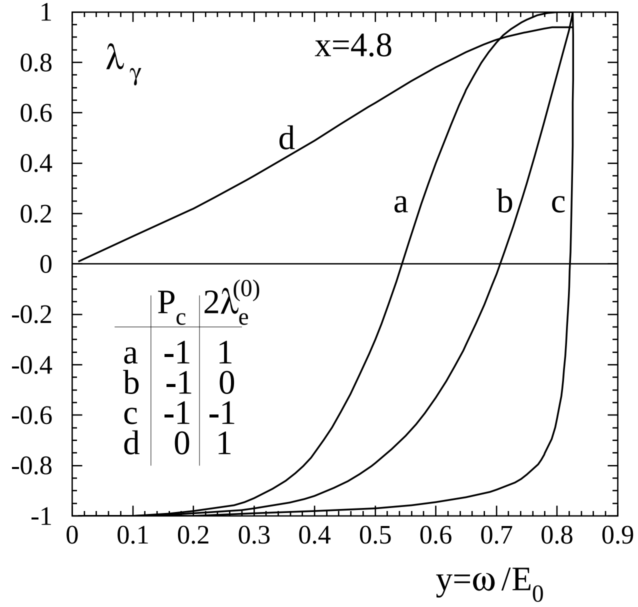
Basics

Photon collider is the option of future Linear Collider (e.g. ILC) based on the laser photon backscattering on accelerated electrons of e-beam

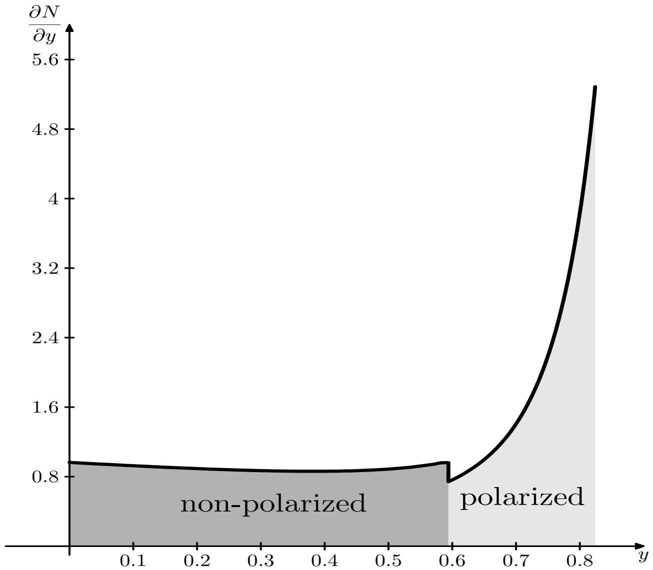


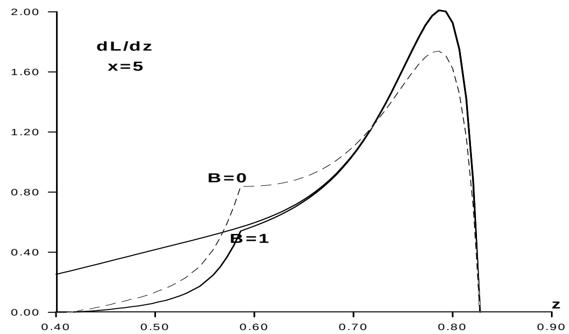
Main process – Compton effect, important parameter $x = \frac{4E\omega_0}{m_e^2} \approx 5$ for ILC and suitable laser, $E_{\gamma max} = \frac{x}{x+1}E$.





Real spectrum of luminosity with taking into account details of set-up and rescatterings is more complex. At $E_\gamma > E_{\gamma max}/2$ it is more or less universal with good polarization. At lower energies rescatterings are dominant, universality is absent, photons are nonpolarized





Approximate model spectra and luminosity distribution over $z = \sqrt{E_{\gamma 1} E_{\gamma 2}/E^2}$.

Charge asymmetry in $\gamma\gamma \to \mu^+\mu^- + \nu$'s $\gamma\gamma \to W^{\pm}\mu^{\mp} + \nu$'s with polarized photons

• Charge asymmetry in processes like

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

appears due to P nonconservation in the SM.

• 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%). We consider such cascade processes.

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

(1) 3 double-resonant diagrams (DRD)

(2) 4 single-resonant diagrams (SRD)

(3) 4 single resonant diagrams with ν exchange

(5) 2 multi-peripheral non-resonant diagrams

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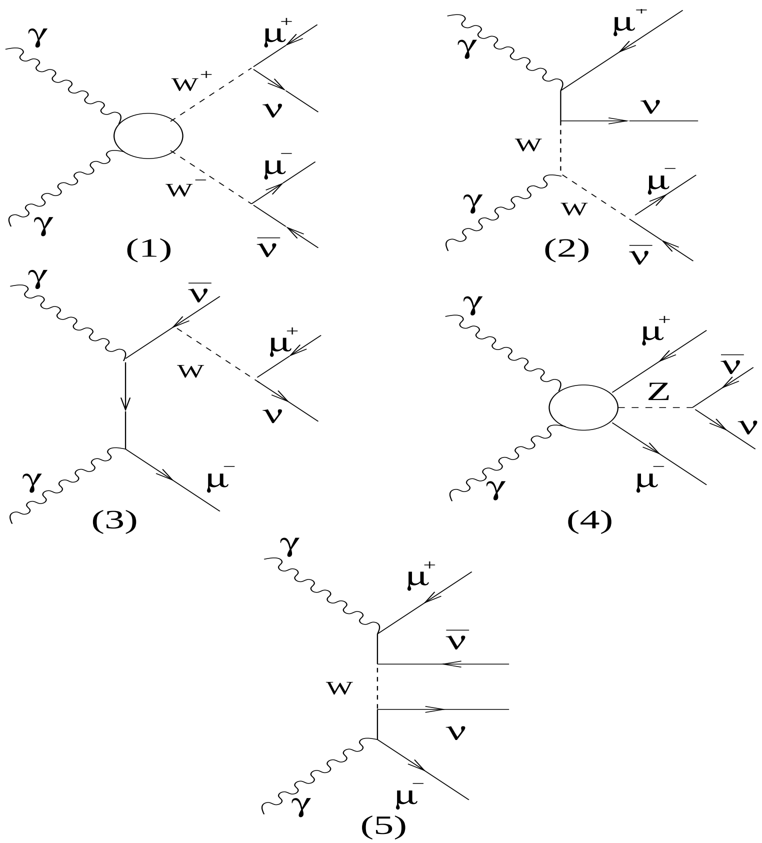
- SRD (2)/DRD (1) is about 5%.
- The interference SRD, DRD is destructive.
- (3),(4) and (5)/DRD (1)$\ll 1$.
- DRD contribution covers almost 98.7 % cross section.

(The $\gamma\gamma \to W^+\mu^-\bar{\nu}$ is described by only first 3 groups.)



We used CalcHEP for calculations.

For each observed particle:

- Cut in escape angle θ

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

- Cut in transverse momentum $p_\perp$:

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

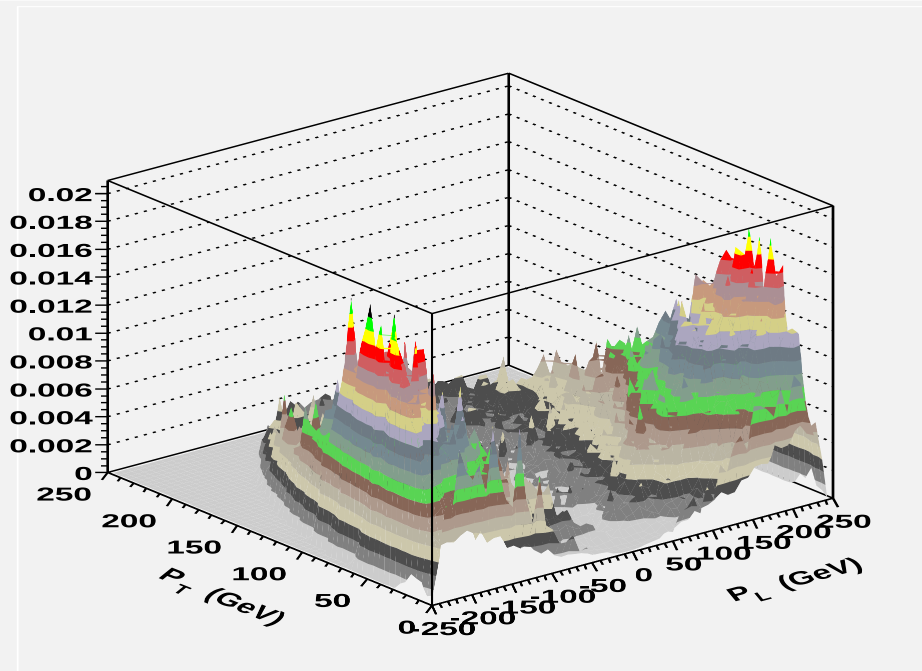
and higher $p^c_{\perp\mu}$ up to 80 GeV.

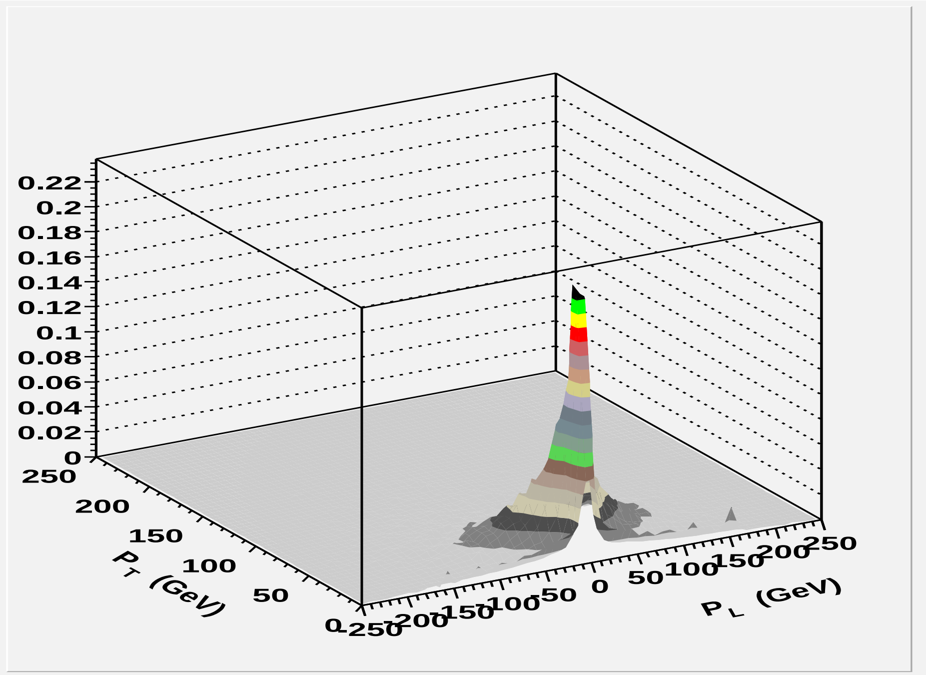
These simultaneous cuts allow many backgrounds to be eliminated.

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

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, $\gamma_-\gamma_-$

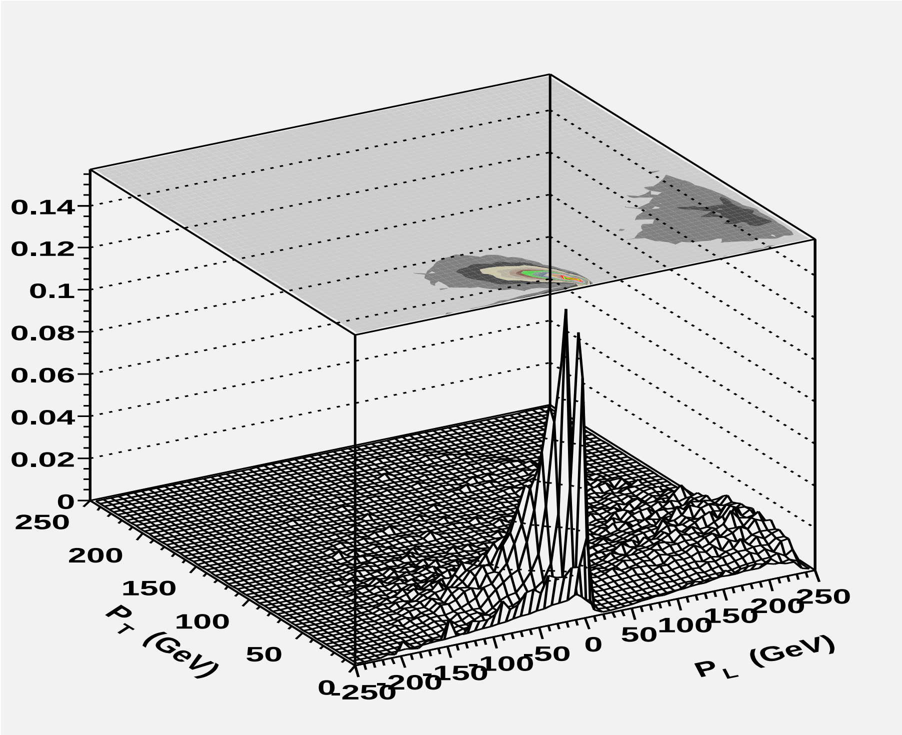


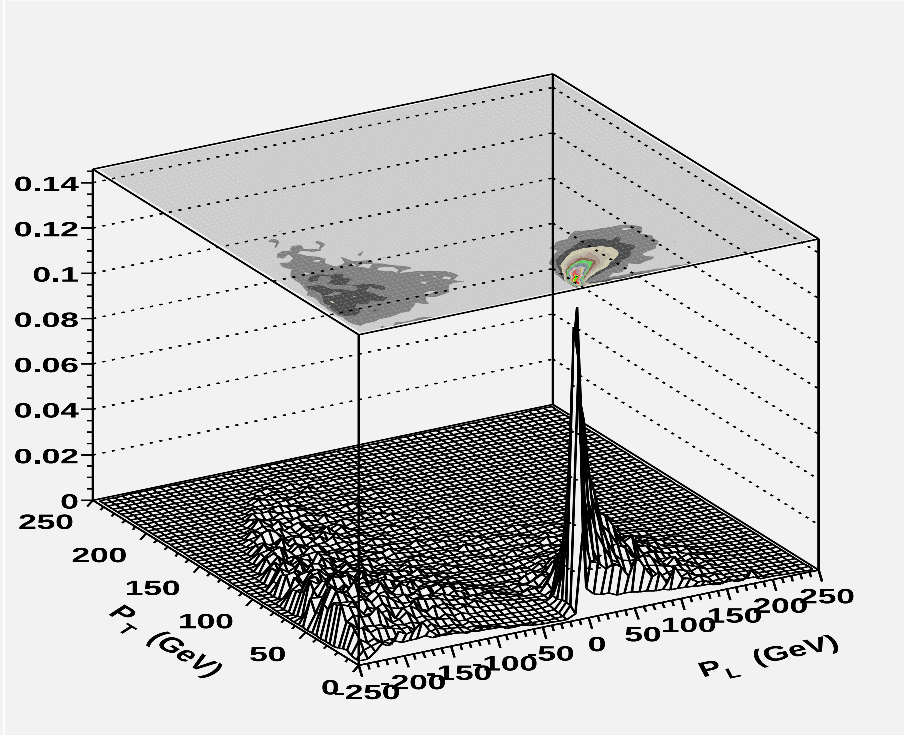


Negative μ distribution.

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:

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

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

$$\Delta_L = \frac{P_{L+}^{-} - P_{L+}^{+}}{P_{L+}^{-} + P_{L+}^{+}}, \qquad \Delta_T = \frac{P_{T+}^{-} - P_{T+}^{+}}{P_{T+}^{-} + P_{T+}^{+}}.$$

• 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.

• Monte Carlo simulations have statistical uncertainty $\delta P_{L,T}, \delta\Delta_{L,T}$ similar to experimental.

$\gamma_{\lambda_1}\gamma_{\lambda_2}$	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 $\gamma_{\lambda_1}\gamma_{\lambda_2} \to W\mu\nu$. Monochromatic case.

We also studied inaccuracy of DRD approximation for various asymmetries.

• Inaccuracy of DRD approximation in $\gamma\gamma \to W\tau\nu$ for $P_{L,T}$ and $\Delta_{L,T}$ quantities $\lesssim 5\%$.

• Inaccuracy for $\gamma\gamma \to W\tau\nu \to W\mu\nu\nu\nu$ is $\lesssim 0.17 \cdot 5\% = 0.85\%$.

– within statistical MC inaccuracy for 10^6 events.

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

Essential feature

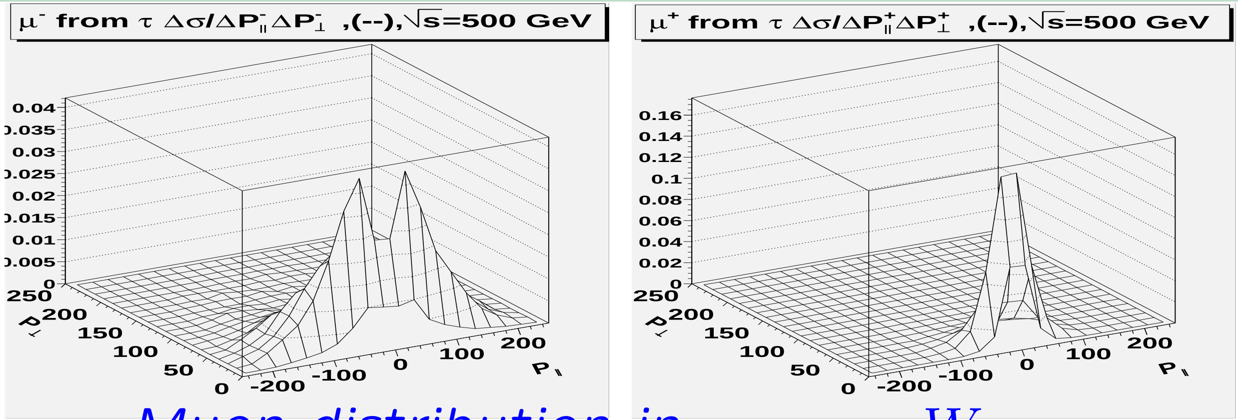
Decay $\tau \to \mu\nu_\tau\nu_\mu$ involves 3 particles,

the effective mass of the $\nu\bar{\nu}$ system $m_{\nu\nu}$ varies from 0 to m_τ

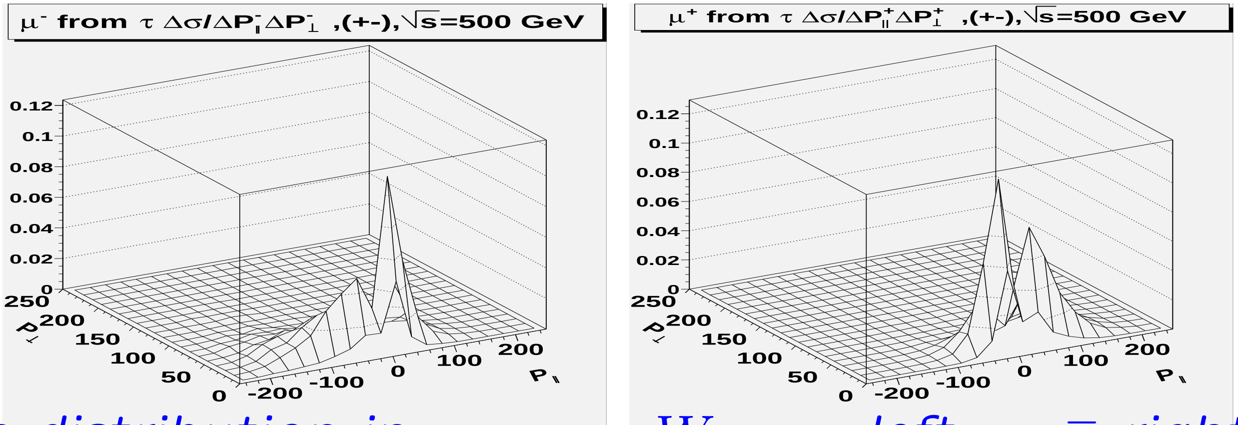
$\Rightarrow$ the μ distribution is *contracted* in comparison with τ distribution:

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

Distributions of μ in cascade process

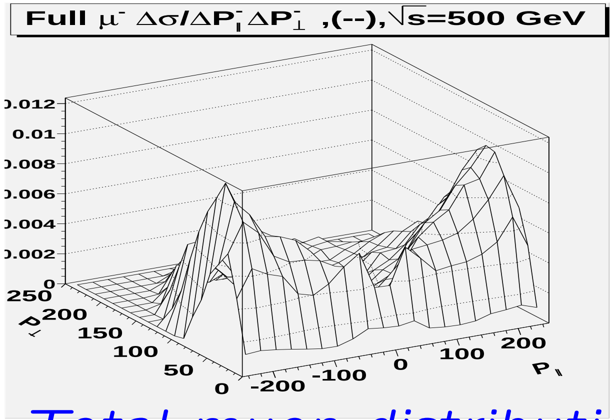


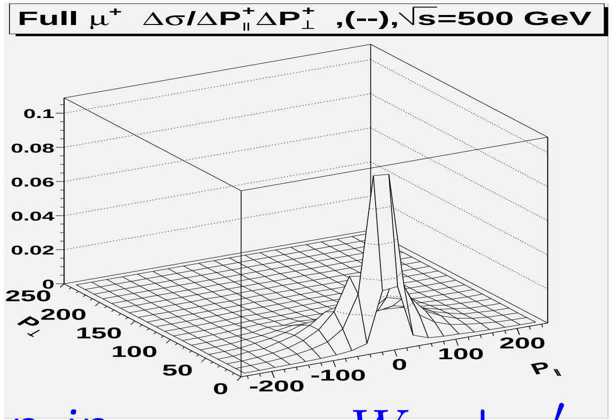
Muon distribution in $\gamma_-\gamma_- \to W\mu\nu\nu\nu$



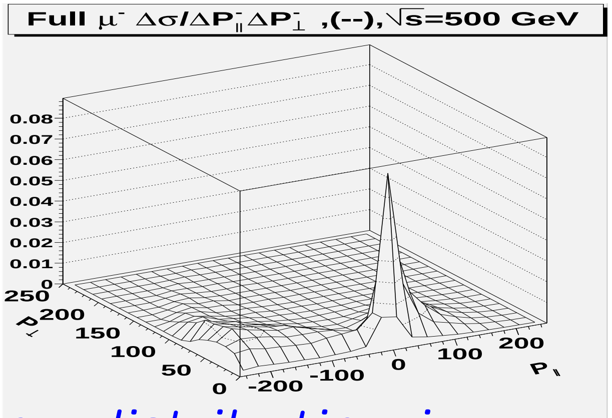
Muon distribution in $\gamma_+\gamma_- \to W\mu\nu\nu\nu$ *left* $-\ \mu^-$,*right* $-\mu^+$

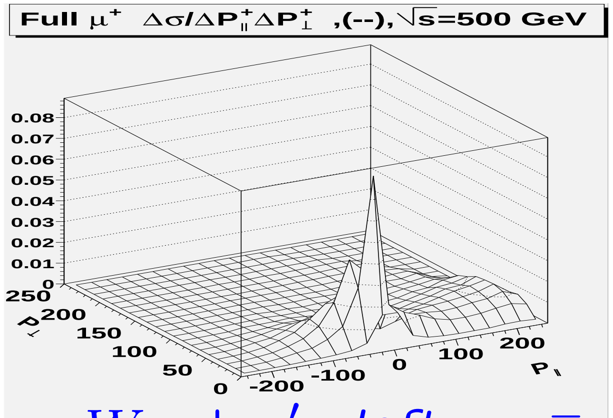
Entire distributions of μ





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





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

• Cascade process changes μ distribution only at small momenta.

• Asymmetry parameters decrease by $\lesssim$ 3%

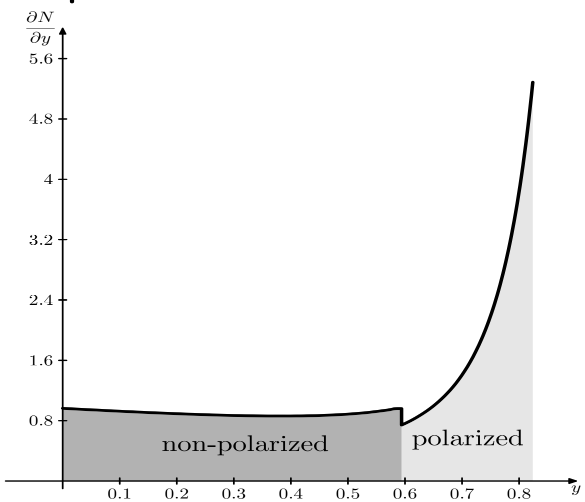
$\gamma_{\lambda_1}\gamma_{\lambda_2}$	N	P_N^-	P_N^+	Δ_N
$\gamma_-\gamma_-$	L	0.548	0.164	0.539
	T	0.311	0.142	0.374
$\gamma_+\gamma_-$	L	0.199	0.513	-0.440
	T	0.152	0.232	-0.207

Total charge asymmetry quantities.

• Applied cuts reduce the contribution of cascade process stronger than the main contribution $\Rightarrow$ *reduce* inaccuracy of DRD approximation in the description of charge asymmetry with growth of $p_{\perp\mu}^c$.

Effect of photon non-monochromaticity

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 an ideal case (Ginzburg, Kotkin). At lower energies factorization is broken, polarization disappears. Details depend on real collision scheme strong.



To IMITATE, we used factorized spectra – for $E_\gamma > E_\gamma^{max}/\sqrt{2}$ mentioned 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 $\delta\Delta_N$	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%	0.365 0.31%	0.157 0.22%	0.398 0.18%
	T	0.333 0.61%	0.159 0.28%	0.335 0.44%	0.284 0.38%	0.179 0.11%	0.228 0.81%
$\gamma_+\gamma_-$	L	0.223 0.82%	0.609 0.19%	-0.463 0.47%	0.174 0.24%	0.338 0.28%	-0.321 0.43%
	T	0.164 0.08%	0.262 0.31%	-0.231 0.76%	0.200 0.09%	0.236 0.16%	-0.082 0.42%

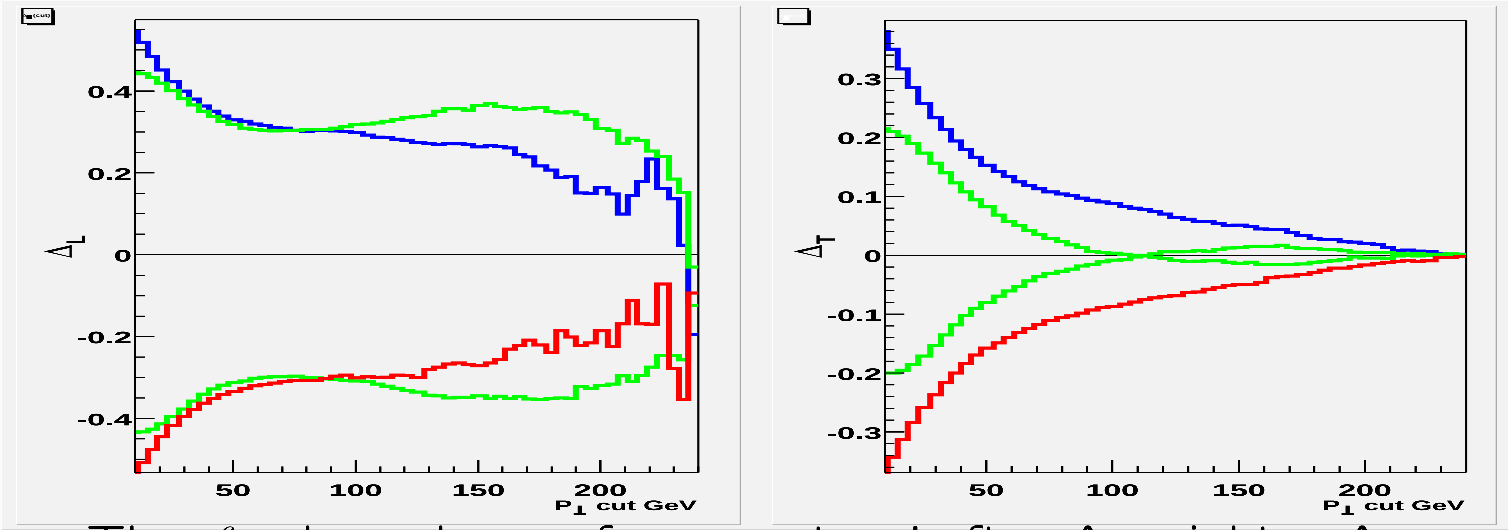
Monochromatic case   *Non-monochromatic case*

Charge asymmetry quantities and statistical uncertainties for $\gamma_{\lambda_1}\gamma_{\lambda_2} \to W\mu\nu$,cut =10 GeV.

In the non-monochromatic case charge asymmetry quantities are reduced typically by a factor 1.3-1.5, their statistical uncertainties vary not so strong.

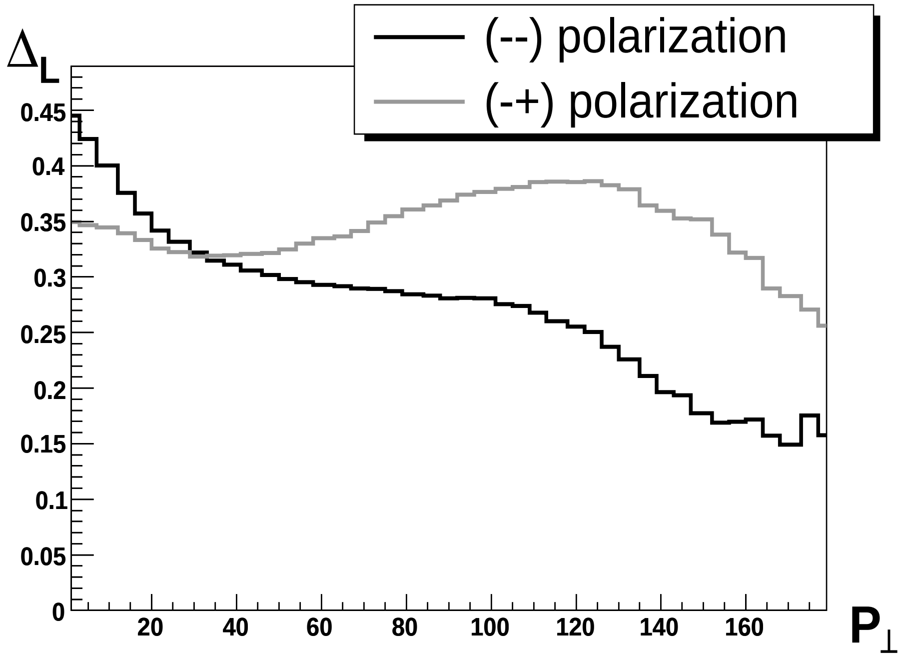
Dependence on cut $p^c_{\perp\mu}$

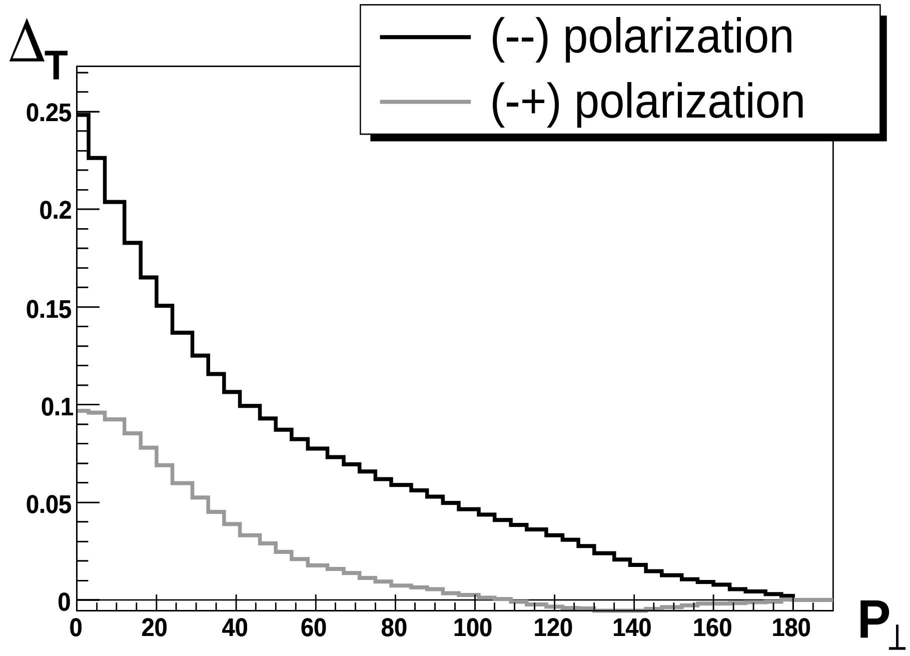
New Physics is expected to be switched on at large transverse momenta. We study the dependence of asymmetry on the cut $p^c_{\perp\mu}$.



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 mentioned decreasing of asymmetry become not so strong with growth of cut momentum for longitudinal asymmetry.

CONCLUSIONS AND PLANS

• Huge and easily observable effect.

• Cascade process weakly affect the asymmetry.

• Introduced quantities (especially Δ_L) large even with large $p^c_{\perp\mu}$ cuts.

• Taking into accont same effects for e^+e^-, $e^+\mu^-$, μ^+e^- enhance statistics by 4 times (it is taken into account).

• Non-monochromaticity of photon spectra decreases the considered asymmetries but retain them large enough.

We plan to consider charge asymmetry for discovery of New Physics effects (e.g. MSSM).