Charge asymmetry in $\gamma\gamma \to \mu^+\mu^- + \nu' s$, $\gamma\gamma \to W^\pm\mu^\mp + \nu' s$ with polarized photons. New results

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• 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.

• Taking into account same effects for e^+e^-, $e^+\mu^-$, μ^+e^- enhance statistics by 4 times.

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

. 19 tree level diagrams:

(1) 3 double-resonant diagrams (DRD),

$\sigma_d \sim (\alpha^2/M_W^2) Br^2(W \to \mu\nu)$

(2) 4 single-resonant diagrams (SRD),

$\sigma_{sW} \sim (\alpha^3/M_W^2) Br(W \to \mu\nu) \sim \sigma_d \alpha / Br(W \to \mu\nu)$

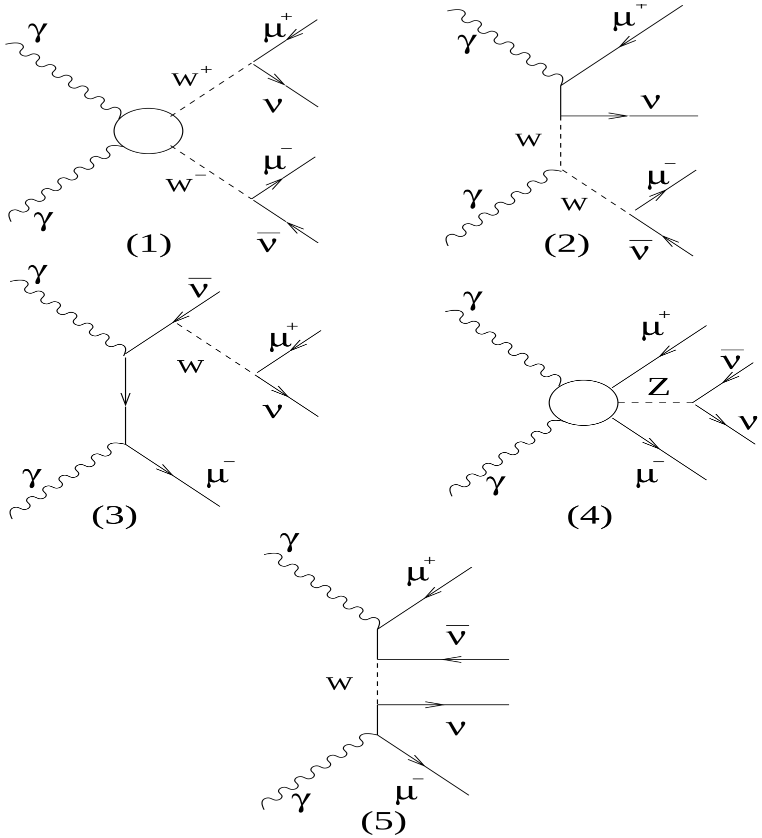
(3) 4 single resonant diagrams with ν exchange in t–channel, $\sigma_{s\mu} \sim (\alpha^3/s) Br(W \to \mu\nu)$

(4) 6 diagrams with radiation of Z boson,

$\sigma_Z \sim (\alpha^3/s) Br(Z \to \nu\bar{\nu})$ *(not for $\gamma\gamma \to \tau\mu\nu\nu$)*

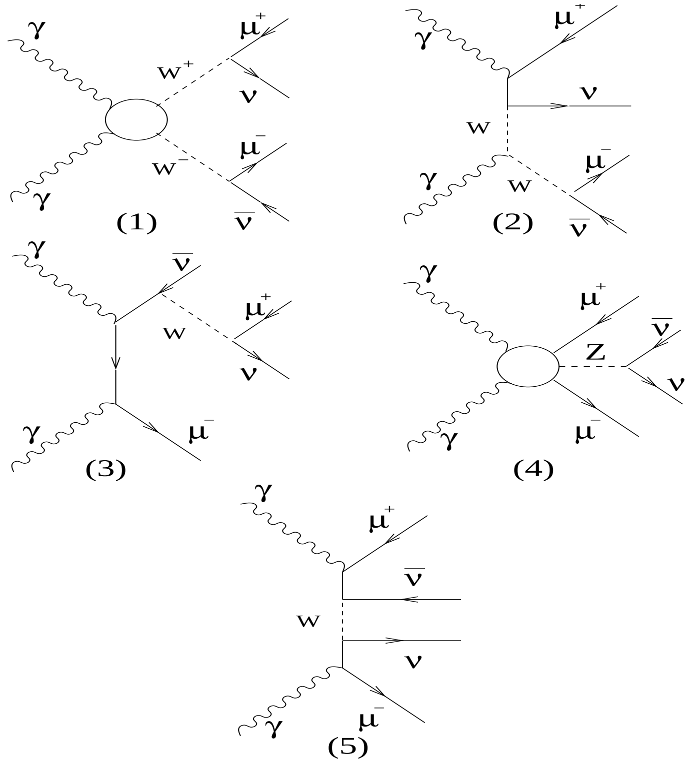
(5) 2 multi-peripheral non-resonant diagrams,

$\sigma_n \sim \alpha^4/M_W^2$



Numerically:

- (3),(4) and (5) are negligible in comparison with DRD (1).
- SRD (2) contribution itself is about 5% of DRD (1).
- The interference of SRD with DRD is destructive.
- DRD contribution covers almost entire 98.7 % cross section.



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 $p_\perp$:

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

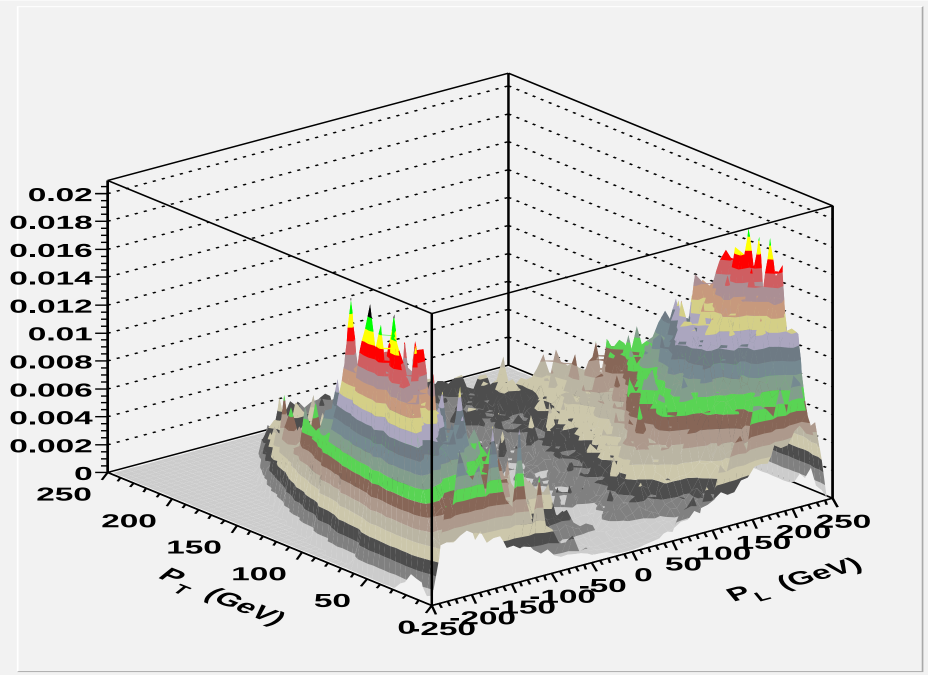
These simultaneous cuts allow many backgrounds to be eliminated.

The number of generated events = anticipated annual number $\simeq 10^6$ events.

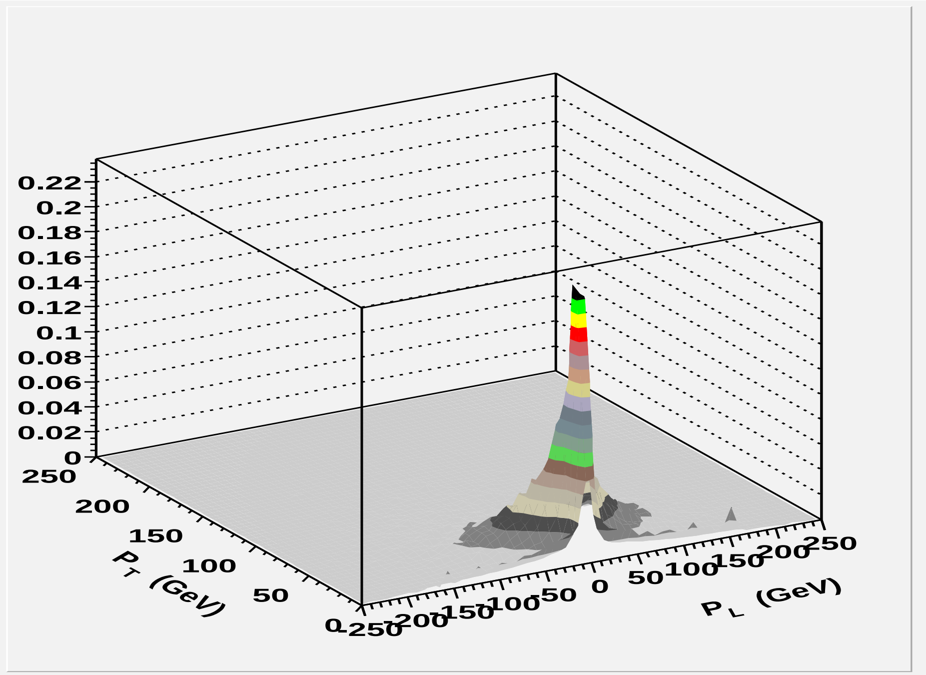
Monte–Carlo event generator IMITATE experiment ⇒
Statistical uncertainty of MC results is the same (or smaller) as in future real experiments with the same number of events.

Difference between distributions of positive and negative muons in $\gamma_{\boldsymbol{\lambda_1}}\gamma_{\boldsymbol{\lambda_2}} \rightarrow \boldsymbol{W\mu\nu}$.

Both photons are left polarized: $\gamma_{-}\gamma_{-}$.



Negative μ distribution.



Positive μ distribution.

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

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

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	0.599 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%

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

Statistical uncertainty is $5 \div 10$ times larger than $1/\sqrt{N}$.

DRD approximation: Only DRD diagrams.

• Inaccuracy of DRD approximation in $\gamma\gamma \to W\mu\nu$ for $P_{L,T}$ and $\Delta_{L,T}$ quantities $\lesssim 5\%$.
• Inaccuracy for $\gamma\gamma \to W\tau\nu \to W\mu\nu\nu\nu$ contribution in this approximation $\lesssim 0.17 \cdot 5\% = 0.85\% \Rightarrow \lesssim$ statistical uncertainty for 10^6 events.

We use this approximation to describe $\gamma\gamma \to \tau\mu\nu$ (not $\gamma\gamma \to \mu\mu\nu$)

Cascade process

Two muons (or $W+\mu$) 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 approximations provide high enough accuracy for our purposes.

In the frame of DRD approximation each τ is produced from W decay. In the rest frame of W the $\tau^{\pm}$ polarisation vector $\pm s/2$ is given by 3-momentum of τ (right or left polarized). In the lab system, where τ momentum is p_τ we have

$$s = \frac{1}{\sqrt{2}} \left(\frac{p_\nu m_\tau}{(p_\tau p_\nu)} - \frac{p_\tau}{m_\tau} \right) .$$

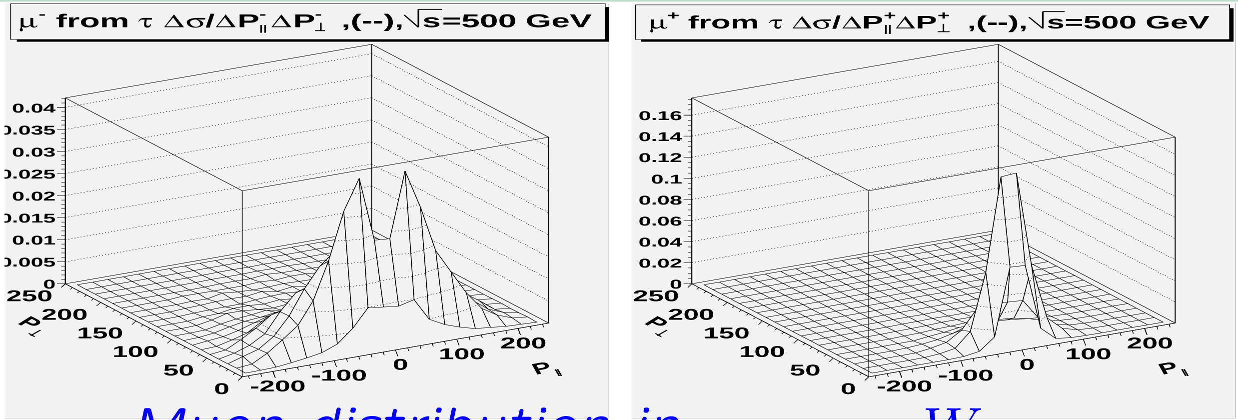
Distribution of produced μ in the lab system is obtained easily by integration over final neutrino, it is expressed via 4-momenta of τ and μ

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

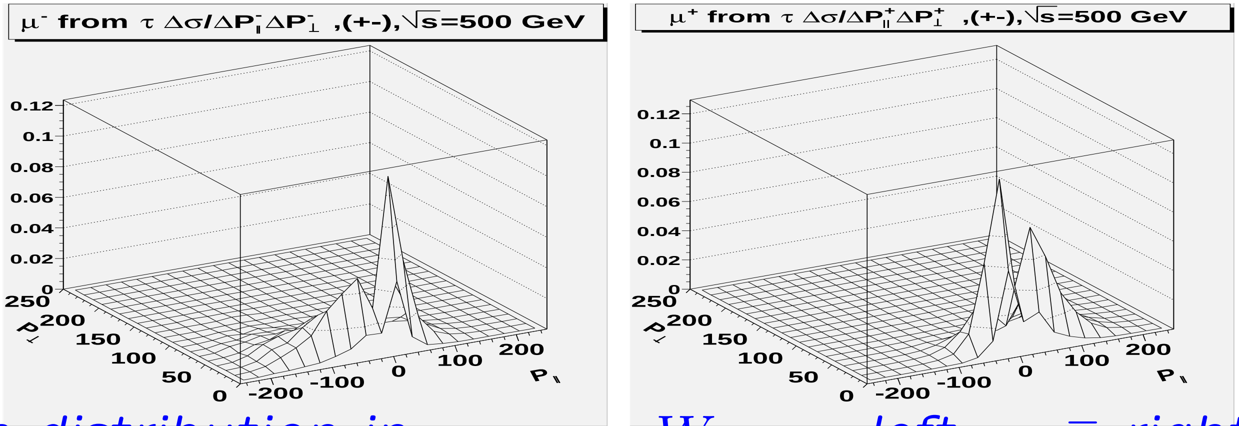
Essential feature

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. Hence, the μ distribution is *contracted* in comparison with τ distribution: $E_\mu \leq E_\tau(1 - m^2_{\nu\nu}/m^2_\tau)$.

Distributions of μ in cascade process

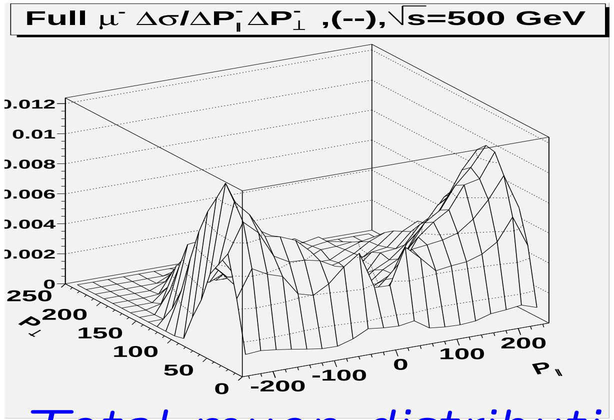


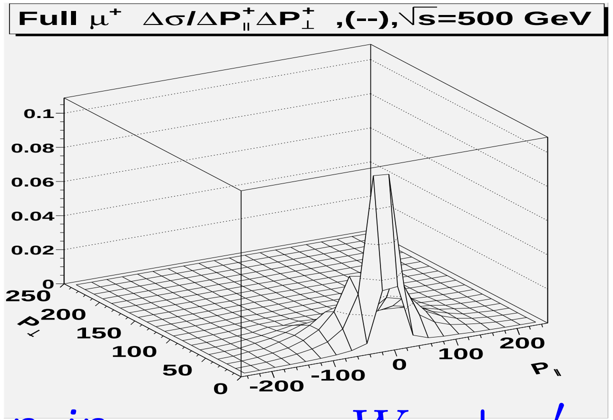
Muon distribution in $\gamma_-\gamma_- \to W\mu\nu\nu\nu$



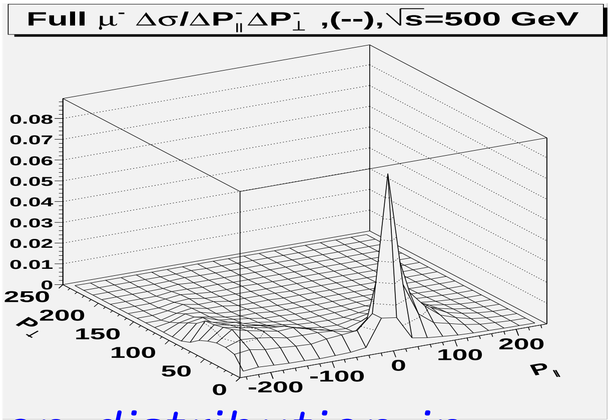
Muon distribution in $\gamma_+\gamma_- \to W\mu\nu\nu\nu$ *left* $-\mu^-$,*right* $-\mu^+$

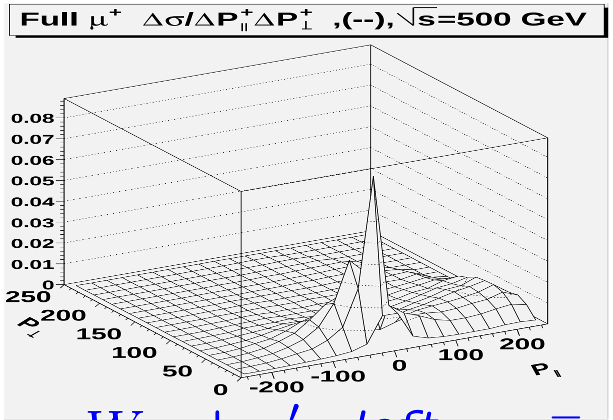
Entire distributions of μ





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%

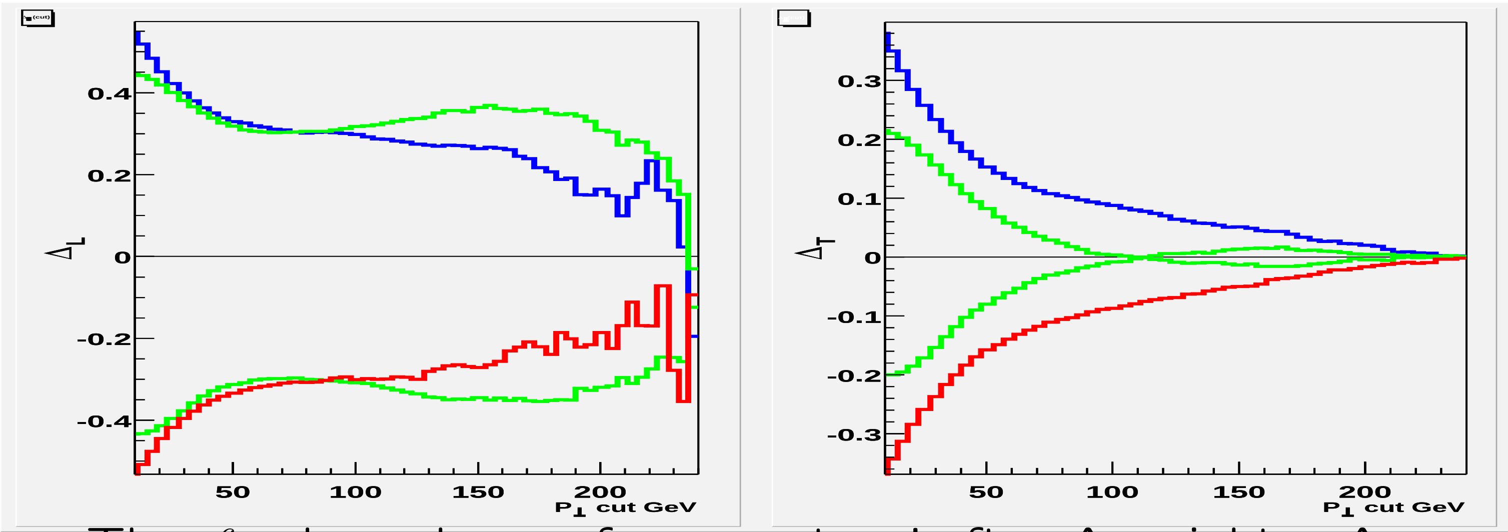
$\gamma_{\lambda_1}\gamma_{\lambda_2}$	N	P_N^-	P_N^+	Δ_N
$\gamma_-\gamma_-$	L	0.548	0.164	0.539
	T	0.311	0.142	0.374
$\gamma_+\gamma_-$	L	0.199	0.513	-0.440
	T	0.152	0.232	-0.207

Total charge asymmetry quantities.

• Cuts in μ transverse momentum 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 $p^c_{\perp\mu}$.

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 – $\gamma_+\gamma_+$

Summary

• Discussed charge asymmetry is huge and easily observable effect.

• Cascade process weakly affect the asymmetry, value of this process decreases with growth of $p_{\perp\mu}$.

• Introduced quantities are large even with large $p^c_{\perp\mu}$ cuts.

■ The used approach for estimate of statistical uncertainty of future experiments looks very effective.

♦ Real photons will not be monochromatic.

Early estimates: non-monochromaticity decreases the considered asymmetries only weakly.