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

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

- 19 tree level diagrams fall into 5 classes:

(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)

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

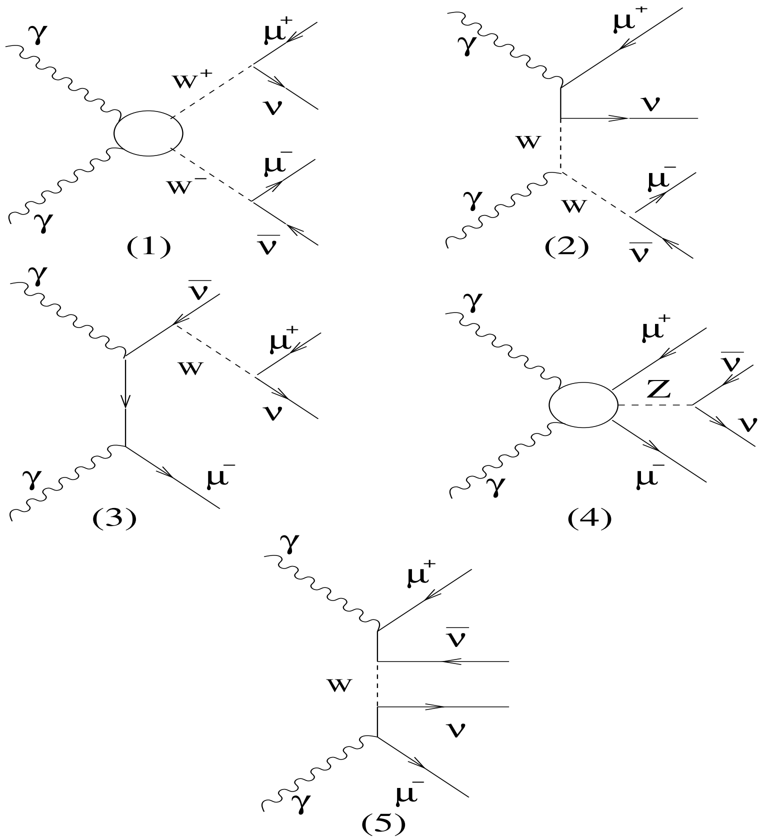
(3) 4 single resonant diagrams with ν exchange in t–channel $\sigma_{s\mu} \sim (\alpha^3/s) Br(W \to \mu\nu)$

(4) 6 diagrams with radiation of Z boson

$\sigma_Z \sim (\alpha^3/s) Br(Z \to \nu\bar{\nu})$

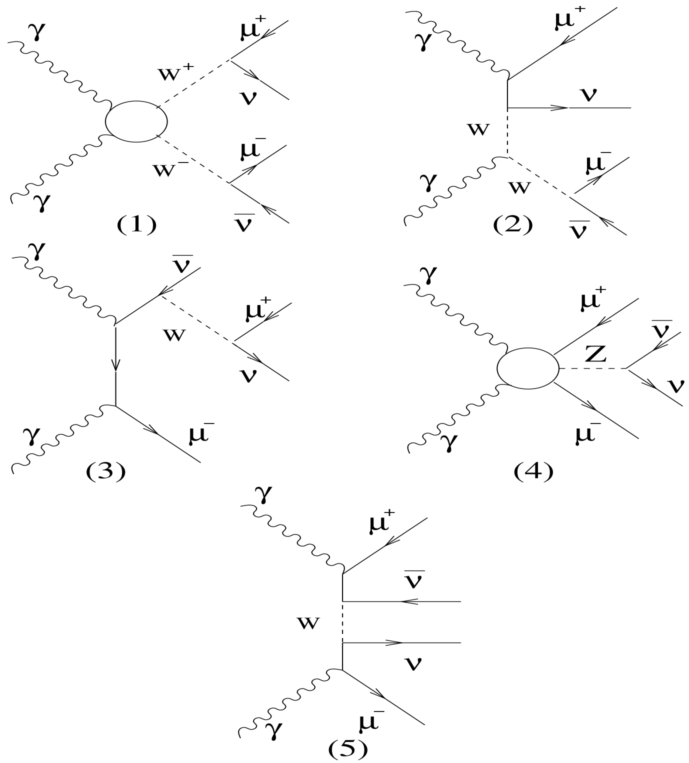
(5) 2 multi-peripheral non-resonant diagrams

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



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.



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

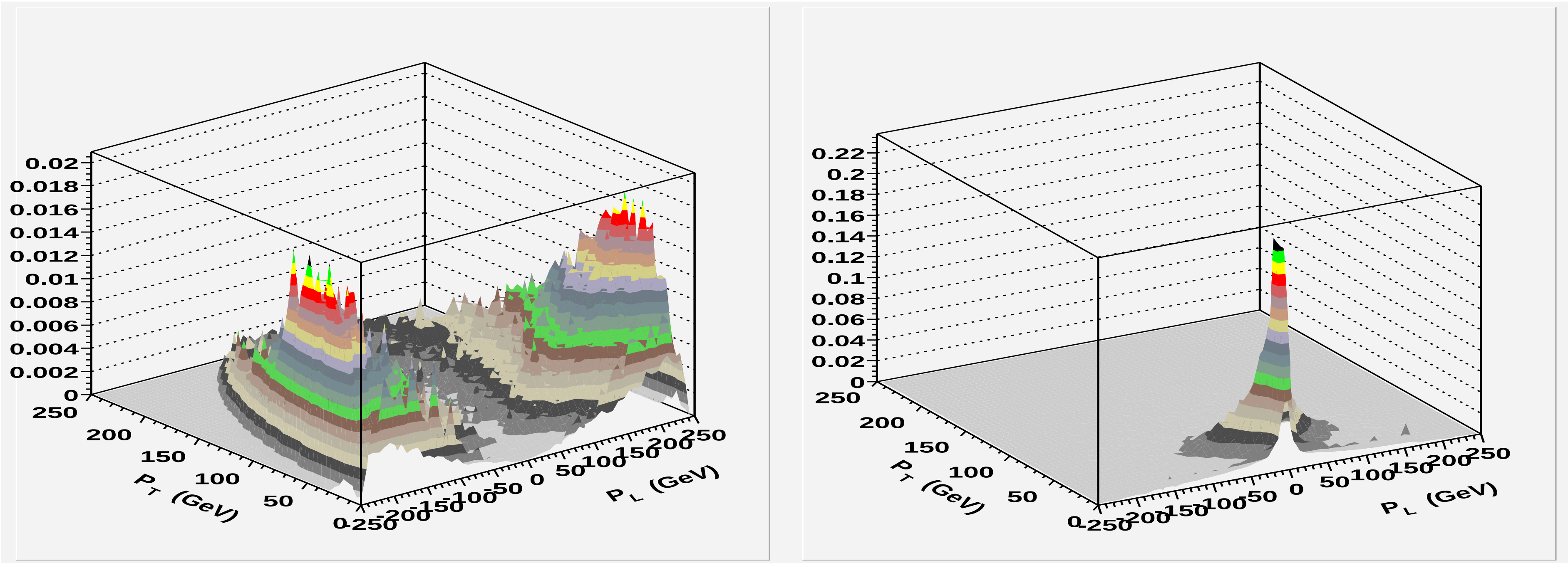
- Charge asymmetry in processes like

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

with polarized photons, appears due to P nonconservation in the SM (photon polarization is "transformed" into asymmetry between distributions of μ^+ and μ^-).

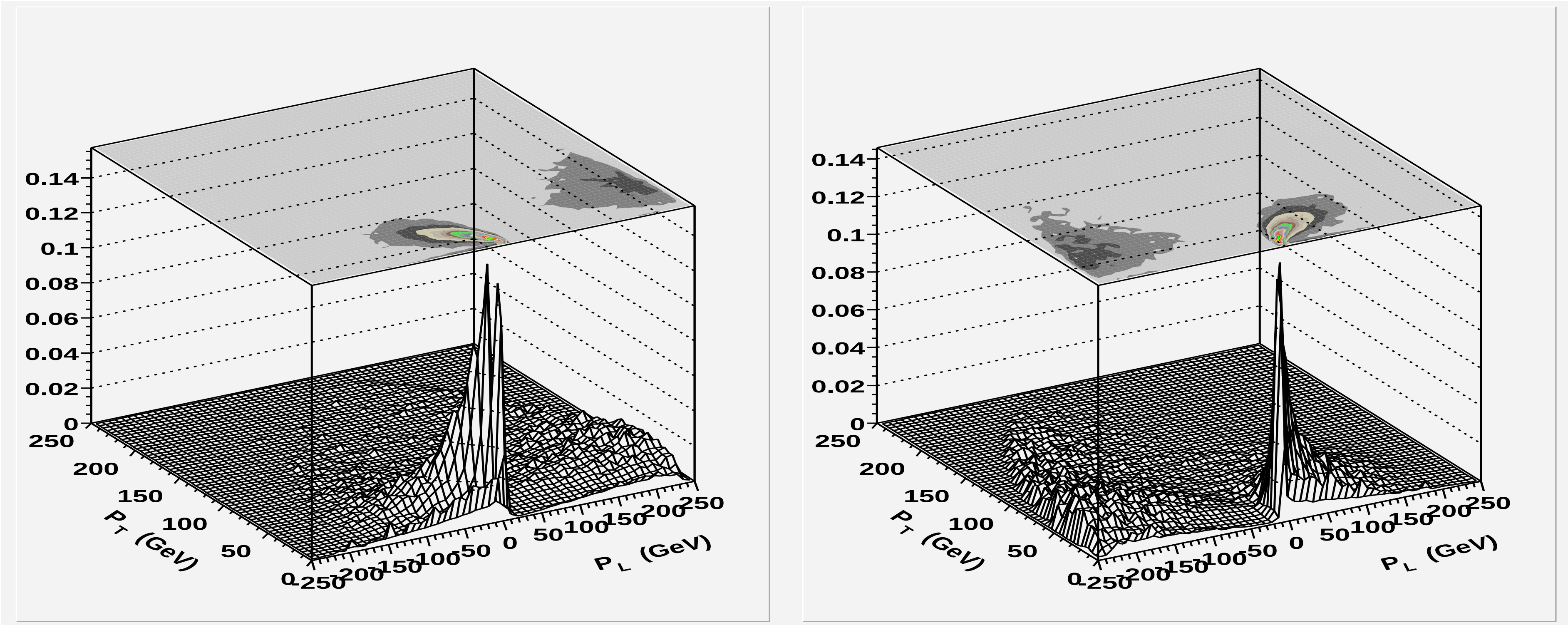
Difference between distributions of positive and negative muons in $\gamma_{\lambda_1}\gamma_{\lambda_2} \to W\mu\nu$.

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.

We used CompHEP/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 $p_\perp$:

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

These simultaneous cuts allow many backgrounds to be eliminated.

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

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

We also studied inaccuracy of DRD approximation for various asymmetries.

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

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.

- Inaccuracy of DRD for $\gamma\gamma \to W\tau\nu \to W\mu\nu\nu\nu \lesssim 0.17 \cdot 5\% = 0.85\%$.
- In the frame of DRD each τ is produced from W decay.
- Therefore 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:

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

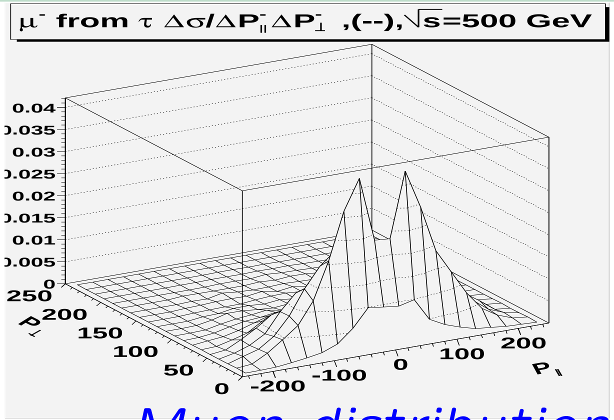
Here k and p are 4-momenta of μ and τ.

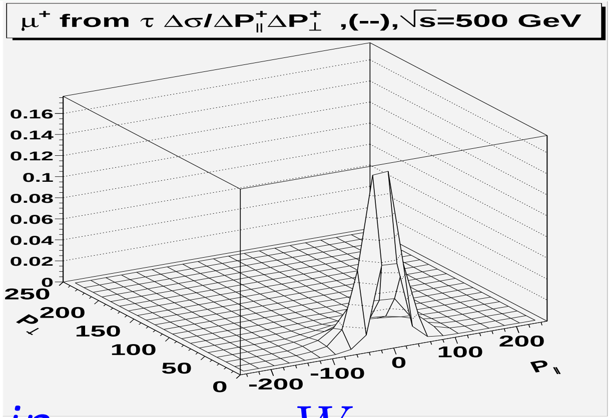
Spin of τ: $\pm s/2$, $s = \frac{1}{\sqrt{2}} \left(\frac{p_\nu m_\tau}{(pp_\nu)} - \frac{p}{m_\tau} \right) \begin{cases} + & \text{for } \tau^+, \\ - & \text{for } \tau^-. \end{cases}$

Essential feature

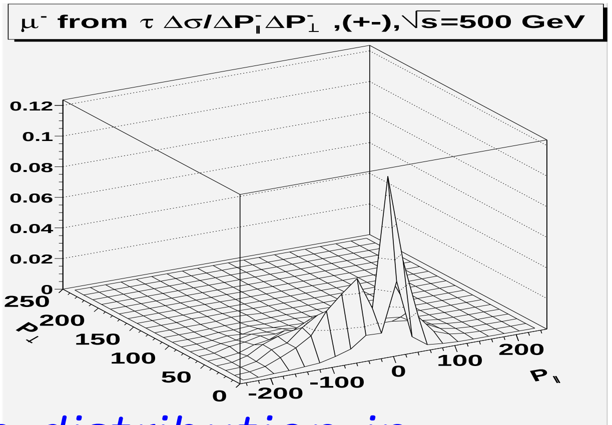
Decay $\tau \rightarrow \mu\nu_\tau\nu_\mu$ involves 3 particles, the effective mass of the $\nu\bar{\nu}$ system $m_{\nu\nu}$ varies from 0 to m_τ. Hence, the μ distribution is *contracted* in comparison with τ distribution: $E_\mu \leq E_\tau(1 - m^2_{\nu\nu}/m^2_\tau)$.

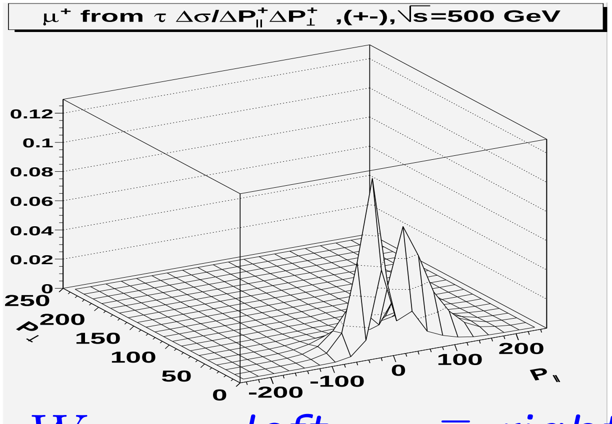
Distributions of μ in cascade process





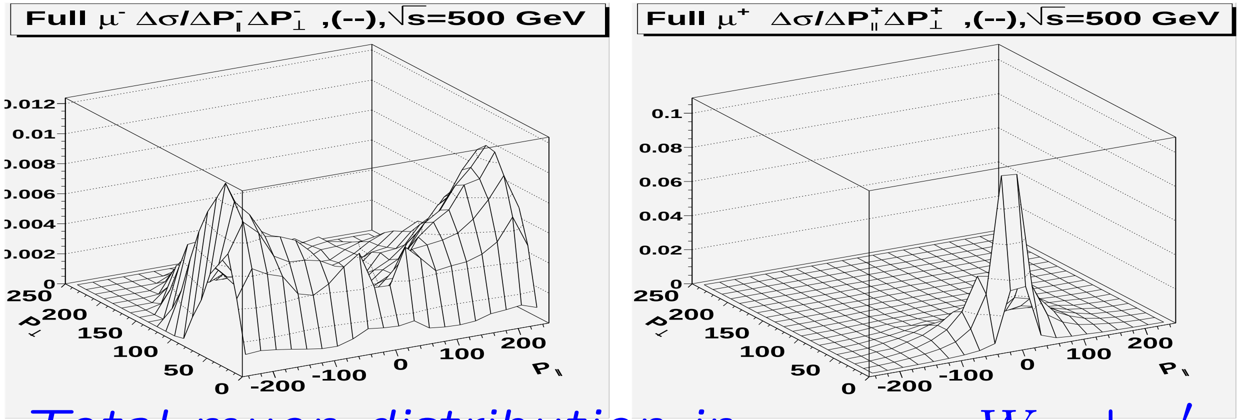
Muon distribution in $\gamma_-\gamma_- \to W\mu\nu\nu\nu$



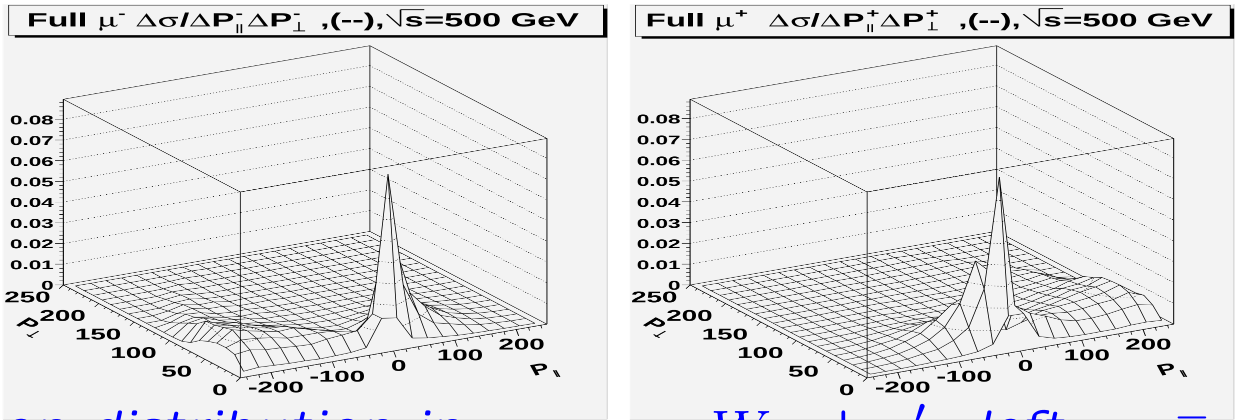


Muon distribution in $\gamma_+\gamma_- \to W\mu\nu\nu\nu$ left $-\mu^-$,right $-\mu^+$

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 $\lesssim 3\%$

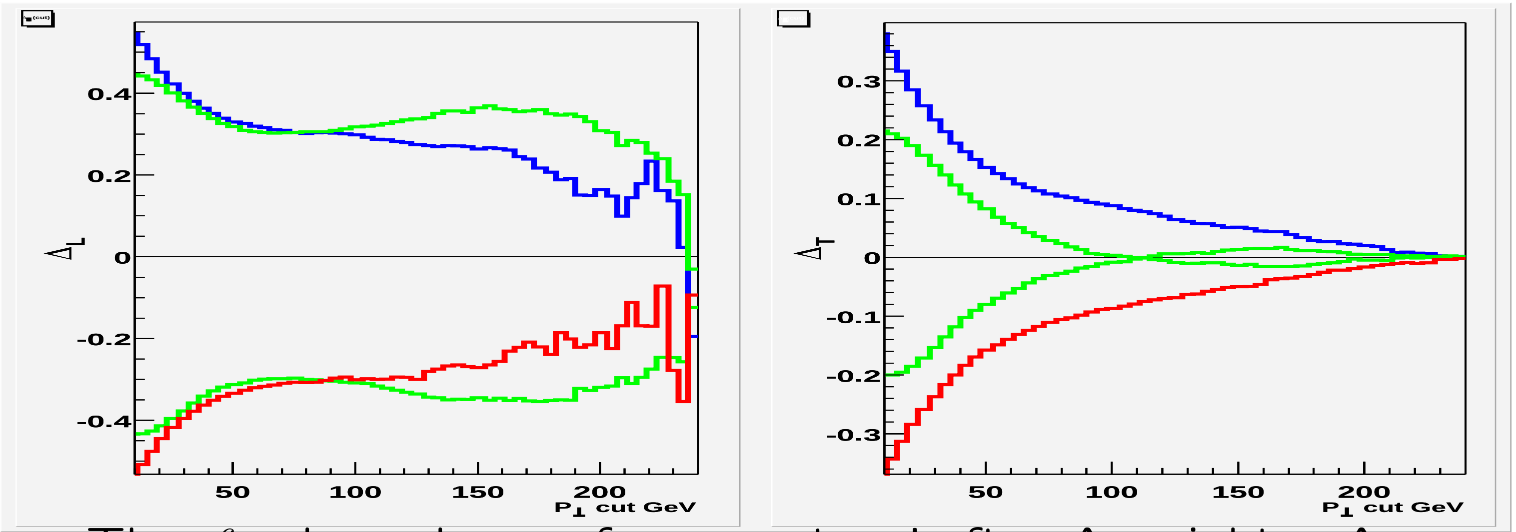
$\gamma_{\lambda_1}\gamma_{\lambda_2}$	N	P_N^-	P_N^+	Δ_N
$\gamma_-\gamma_-$	L	0.548	0.164	0.539
	T	0.311	0.142	0.374
$\gamma_+\gamma_-$	L	0.199	0.513	-0.440
	T	0.152	0.232	-0.207

Total charge asymmetry quantities.

• 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 $p^c_{\perp\mu}$.

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 – $\gamma_+\gamma_+$

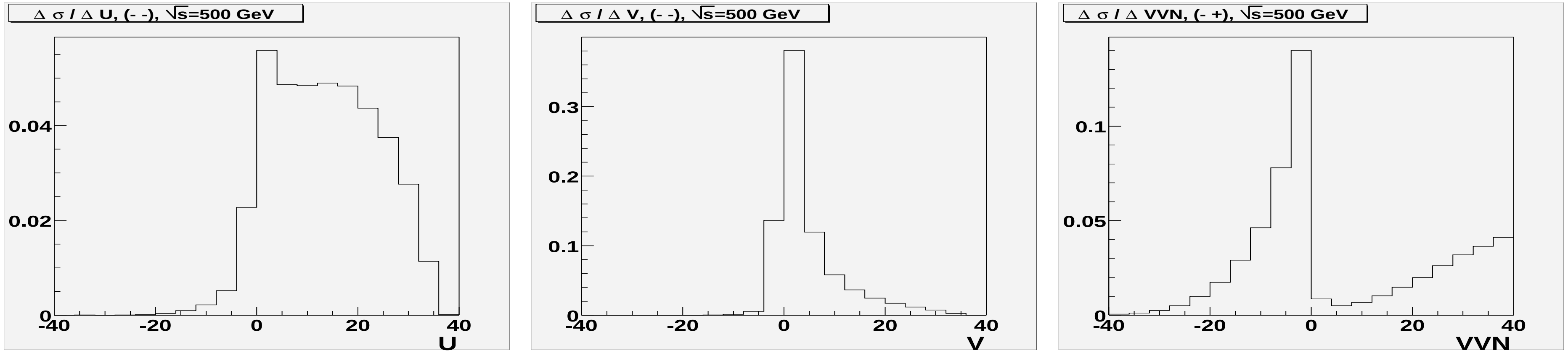
Correlative asymmetry

• Most results are presented for *global asymmetry* – difference between μ^+ and μ^- distributions in $\gamma\gamma \to W^\pm \mu^\pm + \nu$'s processes. It shows main features of studied effect demanding less CPU time.

• *The correlative asymmetry* in μ^+ and μ^- momenta in each $\gamma\gamma \to \mu^+\mu^- + \nu$*'s* event can be more informative in the hunt for New Physics but with lower counting rate.

Some other variables can be more useful :

$$v = \frac{4(p_{\perp+}^2 - p_{\perp-}^2)}{M_W^2}, \quad u = \frac{4(p_{\parallel+}^2 - p_{\parallel-}^2)}{M_W^2}, \quad vvn = \frac{4(p_{\parallel+}\epsilon_+ - p_{\parallel-}\epsilon_-)}{M_W^2}.$$



Distribution in u (left) and v (center) for $\gamma_-\gamma_-$ collision. Right: Distribution in vvn for $\gamma_-\gamma_+$ collision.

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^- enchance statistics by 4 times.

- Real photons will not be monochromatic.

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

- Consider charge asymmetry for discovery of New Physics effects (e.g. MSSM).