Charge asymmetry in $\gamma\gamma \to \begin{matrix} \mu^+\mu^- \\ W^\pm\mu^\mp \end{matrix} + neutrals$ with polarized photons

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Two series of observable phenomena:

- The difference in distributions of μ^+/μ^- (e.g. in $\gamma\gamma \to W^+\mu^- + neutrals/\gamma\gamma \to W^-\mu^+ + neutrals$).
- The violation of symmetry in distributions of μ^+ and μ^- in $\gamma\gamma \to \mu^+\mu^- + neutrals$ in each event (smaller cross sections).

At Photon Colliders high energy photons will be prepared mainly in the states with definite helicity $\lambda_i \approx \pm 1$.
For oral discussion, we distinguish the initial states with $\lambda_1, \lambda_2 = \pm 1$.

The QED cross sections of pair production $\gamma\gamma \to W^+W^-$, $\to \tau^+\tau^-$, $\to \chi^+\chi^-$, etc. depend on the product of photon helicities $\lambda_1\lambda_2$ only and exhibit no charge asymmetry (due to P-invariance of QED). The helicity states of these W, τ or χ depend on photon polarizations. In the subsequent decay of these $W/\tau/\chi$
the momentum distribution of final observable particles (e.g. muons) depend on the parental helicity and charge state $\Rightarrow$ momentum distribution of observed particles (e.g. μ^+ and μ^-) become different $\Rightarrow$

charge asymmetry of final muons related to initial photon polarization state.

The observable effect summarizes effects from various intermediate states $\Rightarrow$ the detailed study of charge asymmetry, related to different mechanisms, in different regions of final phase space is necessary.

This asymmetry is absent for massless intermediate particles due to helicity conservation. Therefore, the value of effect increases with the mass of intermediate particle ($\tau/W/\chi^{\pm}$,...).

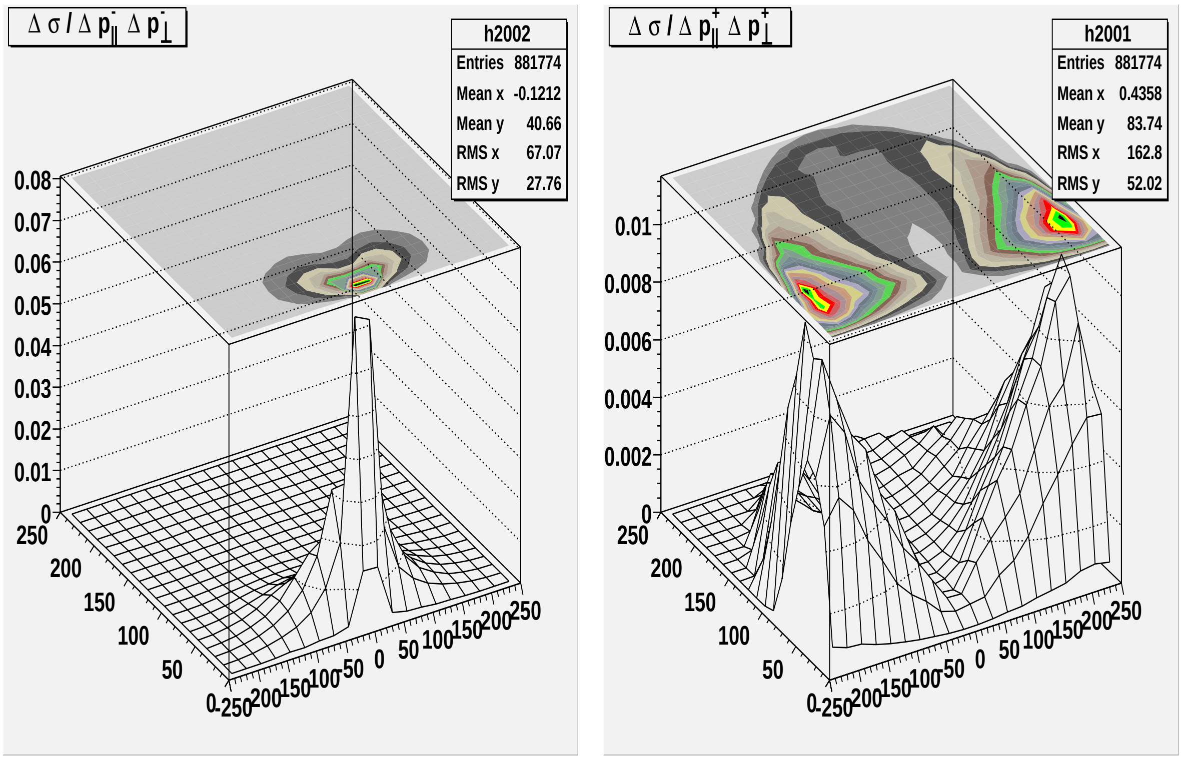
We expect: This charge asymmetry will be sensitive to New Physics effects. For the first step, we consider in detail these effects in $\mathcal{SM}$.

$$\gamma\gamma \to \mu^+\mu^-\nu_\mu\bar{\nu}_\mu$$

(Monochromatic photons.)

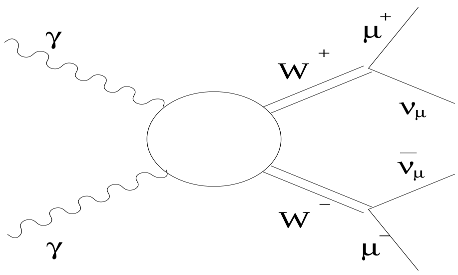
Example: Initial photon state – –

$\sqrt{s} = 500$ GeV.

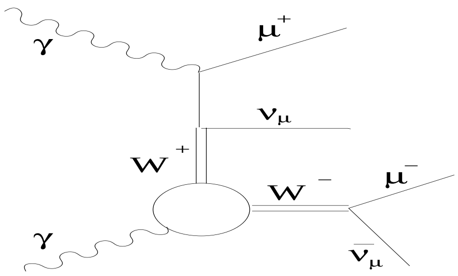


Momentum distributions of negative (left) and positive (right) muons

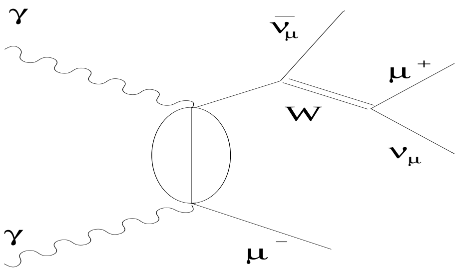
Below main part of figures for $\sqrt{s} = 500$ GeV.



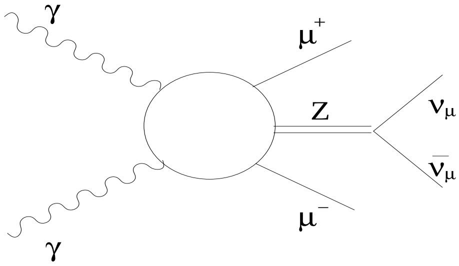
Double resonant.
3 diagrams,
$\sigma_d \sim \frac{\alpha^2}{M_W^2} Br^2(W \to \mu\nu)$ –
numerically 70%.



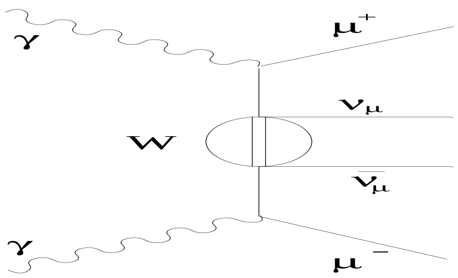
Single resonant 1. $\gamma_1 \leftrightarrow \gamma_2$, $\mu^+ \leftrightarrow \mu^-$ – 4 diagrams,
$\sigma_{s1} \sim \frac{\alpha^3}{M_W^2} Br(W \to \mu\nu)$
– numerically 30%.



Single resonant 2.
2 basic diagrams $\times \mu^+ \leftrightarrow \mu^-$ – 4 diagrams, $\sigma_{s2} \sim \frac{\alpha^3}{s} Br(W \to \mu\nu)$ – *small*.

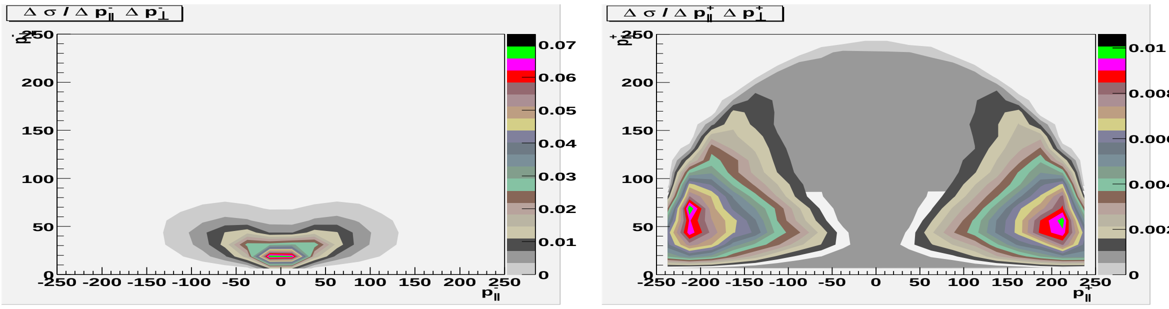


Z pole. 2 basic diagrams with 3 points for Z in each – 6 diagrams,
$\sigma_Z \sim \frac{\alpha^3}{s} Br(Z \to \nu\bar{\nu})$ – *small*.

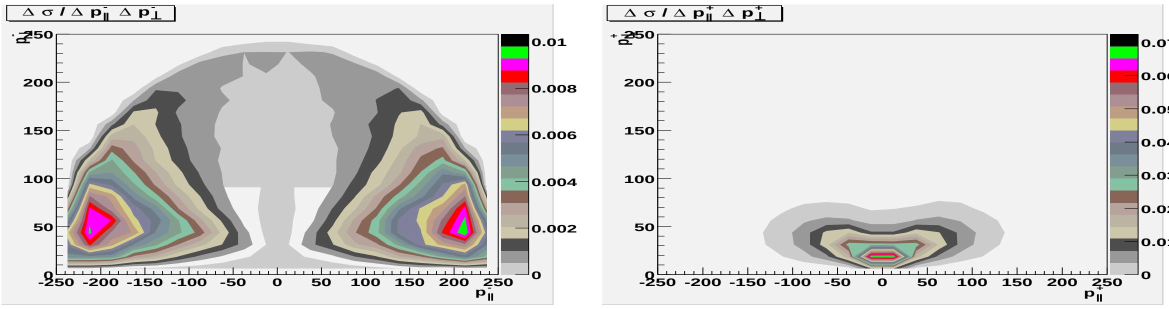


Nonresonant.
$\gamma_1 \leftrightarrow \gamma_2$ – 2 diagrams,
$\sigma_n \sim \frac{\alpha^4}{M_W^2}$ – *small*.

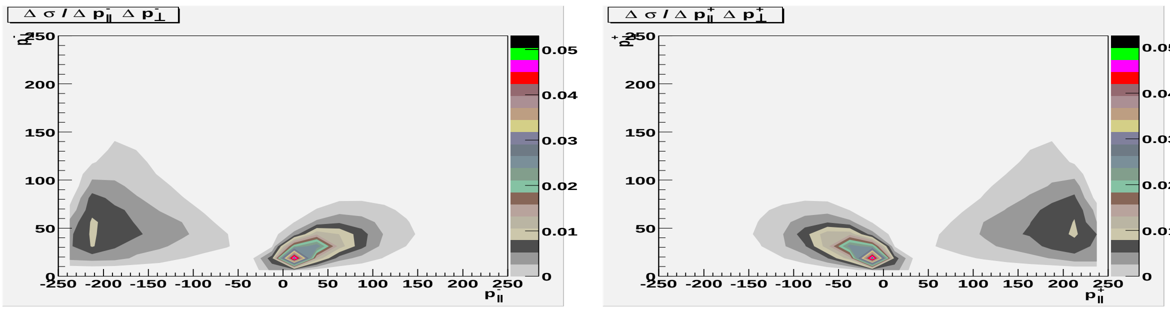
Momentum distributions of negative (left) and positive (right) muons



Initial photon state $--$



Initial photon state $++$



Initial photon state $-+$

Qualitative interpretation

Main contribution is given by double resonant process with W's flying forward.

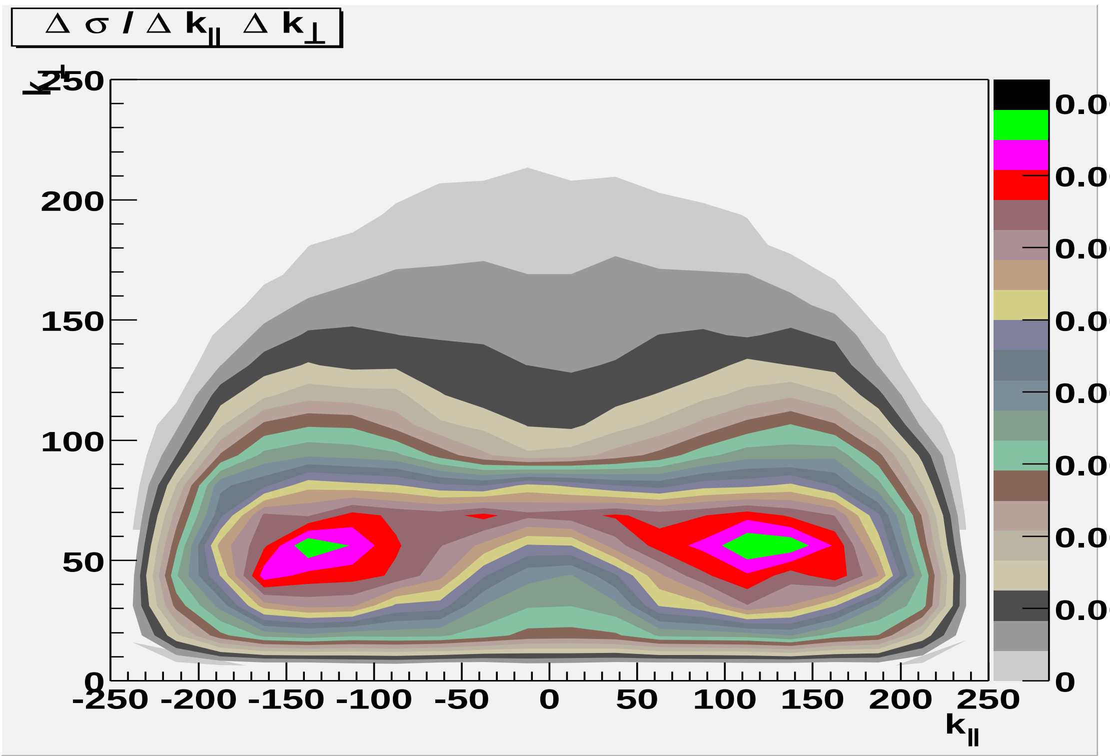
In this case helicities of $W^{\pm}$ coincide with those of initial photons.

W^{-} decay: muons fly opposite to W spin

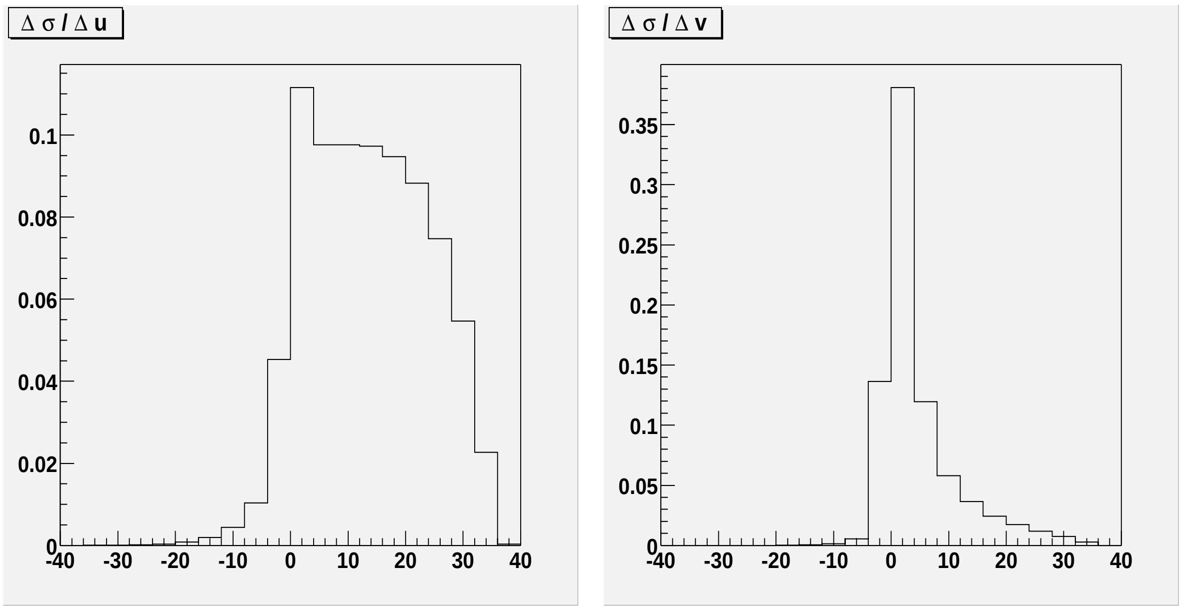
W^{+} decay: muons fly along W spin.

Comment: $\mathcal{CP}$ conservation.

Initial photon state $--$, $\sqrt{s} = 500$ GeV:
Pair distributions for each event.
Distribution in $k = p_+ + p_-$



In $u = p^2_{+\ell} - p^2_{-\ell}$ (left) and in $v = p^2_{+\perp} - p^2_{-\perp}$ (right)

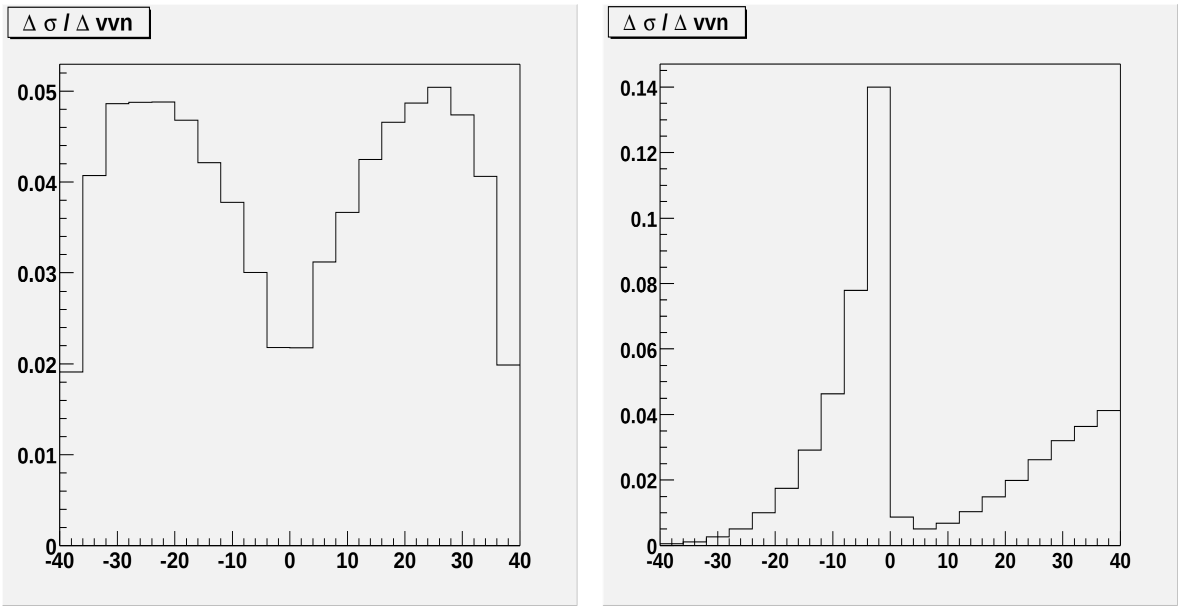


For the total helicity 2 (-+ or +- photon initial states) other variables should be invented.

Distributions in

$v_\ell = 4[p_{+\ell}\varepsilon_{+} - p_{-\ell}\varepsilon_{-}]/M_W^2$

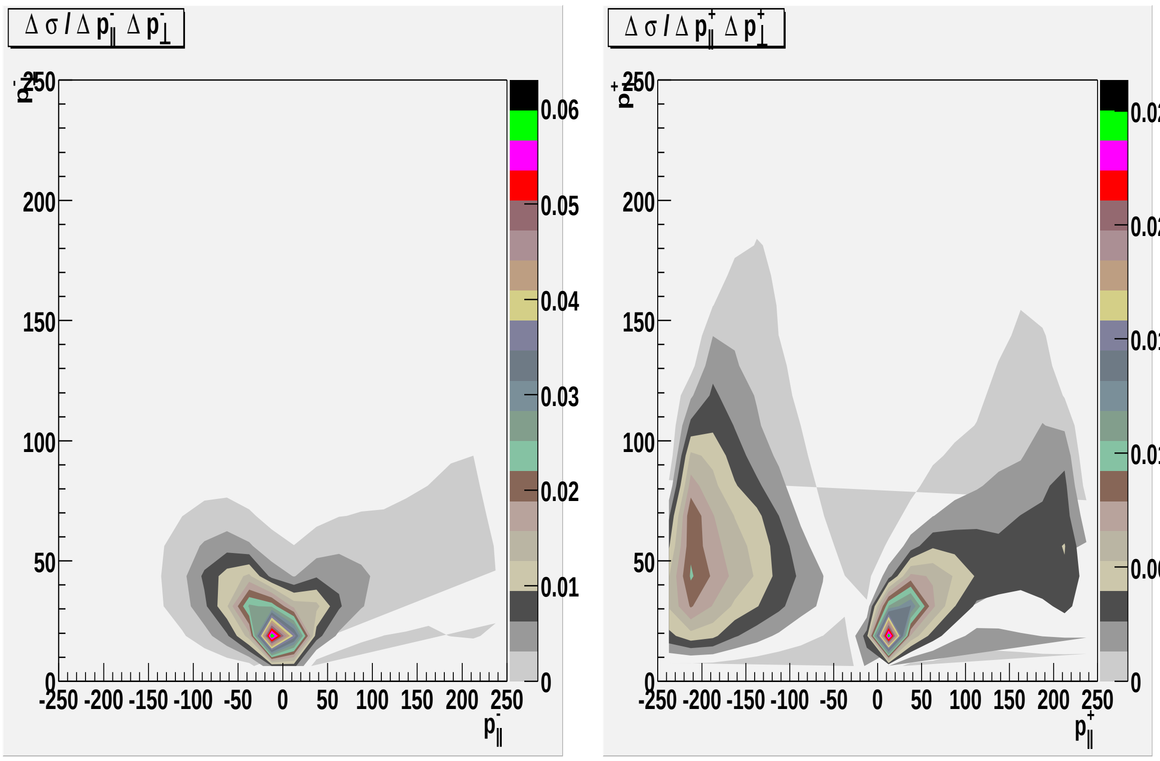
for (- -) (left) and (- +) (right) photon initial states.



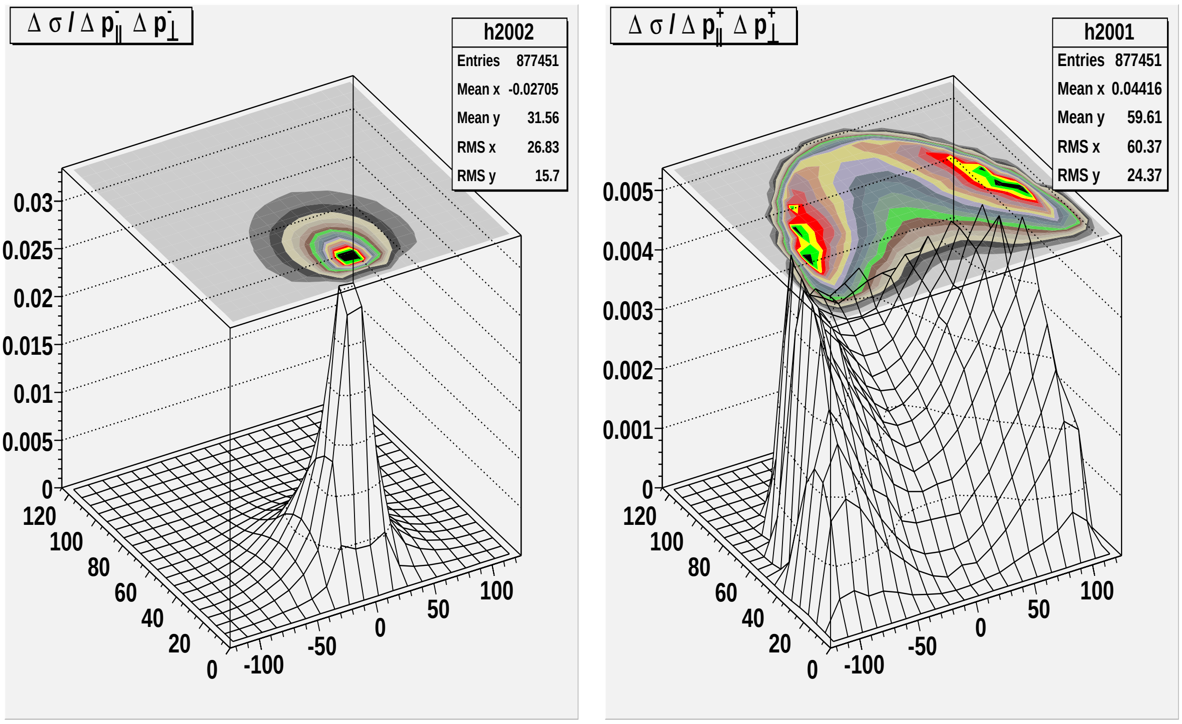
comment

What happens for one polarized and one non-polarized photon?

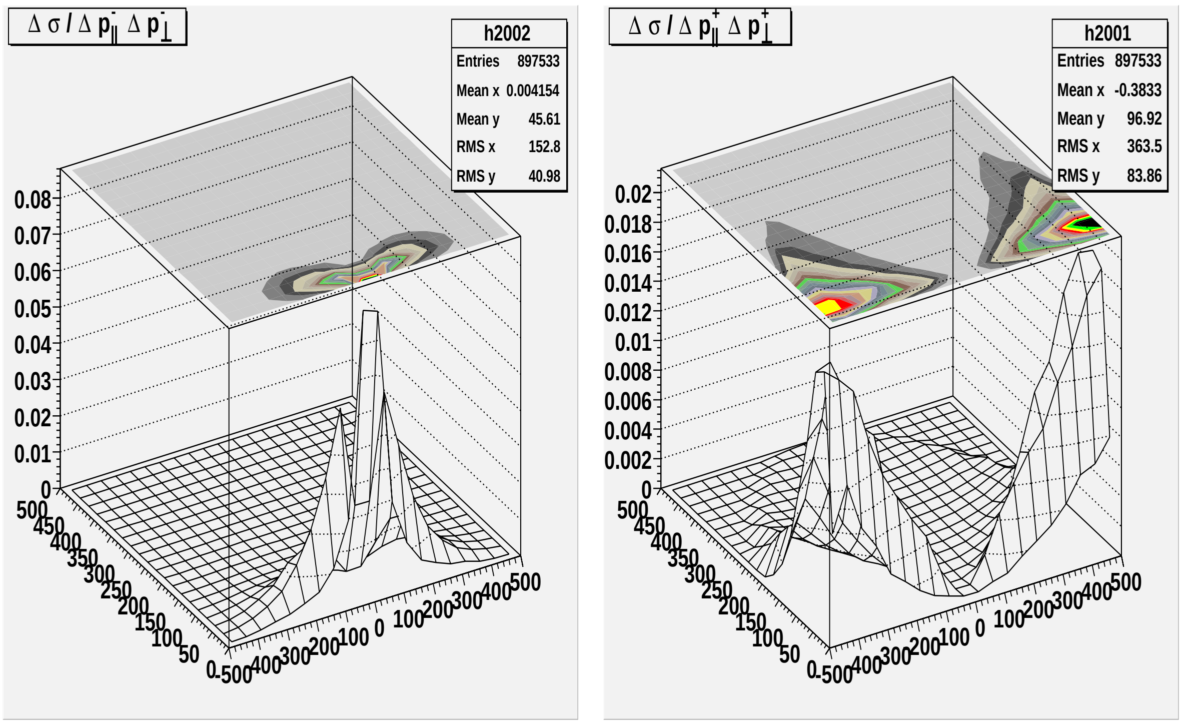
We show the case
0 −(nonpolarized, left polarized).



What happens at variation of beam energy?



$\sqrt{s} = 250$ GeV.



$\sqrt{s} = 1000$ GeV.

General comments. Problems

• Smoothing by initial photon energy spectra.
Only high energy part is essential.

•Relatively small cross sections
$\sigma \approx Br^2(W \to \mu\nu) \cdot \sigma(\gamma\gamma \to W^+W^-) \sim 0.8$ pb.
The same effects for e^+e^-, $e^-\mu^+$, $e^+\mu^-$ final states $\Rightarrow$ factor 4 in cross section summed over these final states.

• Influence of τ decay mode
The similar effects for τ decay change obtained results $(Br(\tau \to \mu\nu\nu) \approx 17\ \%)$. Its computation is not so easy since
◊ we have here at least 6 fermions in final state,
◊ momentum distribution for muon depend on helicity state of intermediate τ,
◊ very narrow intermediate state.

One can overcome many of above difficulties in

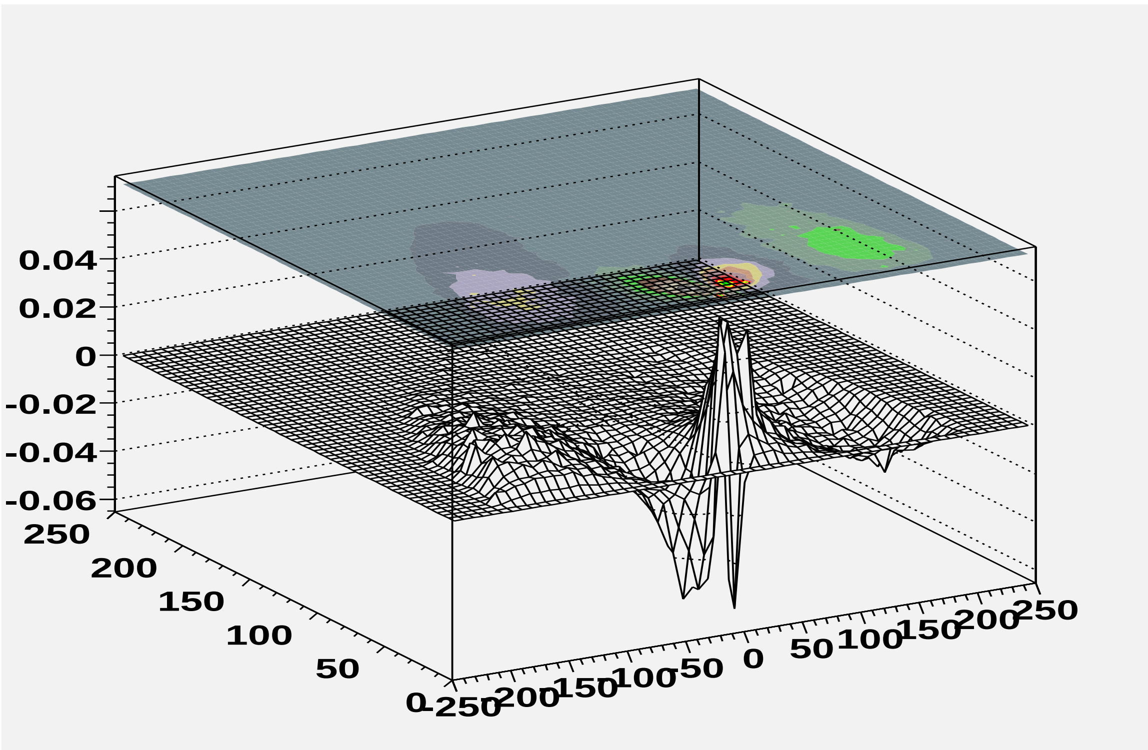
$\gamma\gamma \to W^{\pm}\mu^{\mp}\nu$ (W is $q\bar{q}$ state with $M_{q\bar{q}} = M_W \pm 5$ GeV)

with comparison of spectra for μ^+ and μ^-

Nonmonochromatic photons.

Effect of anomalous interactions.

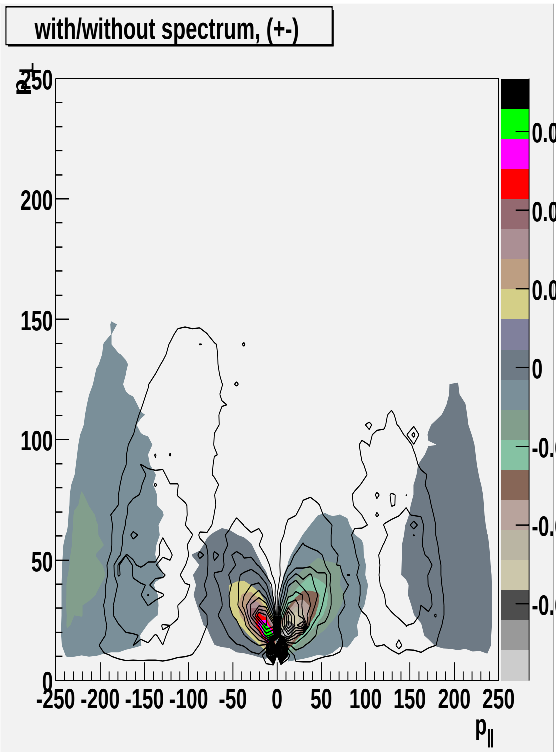
Total cross section for muon and electron decay modes is about 28 pb

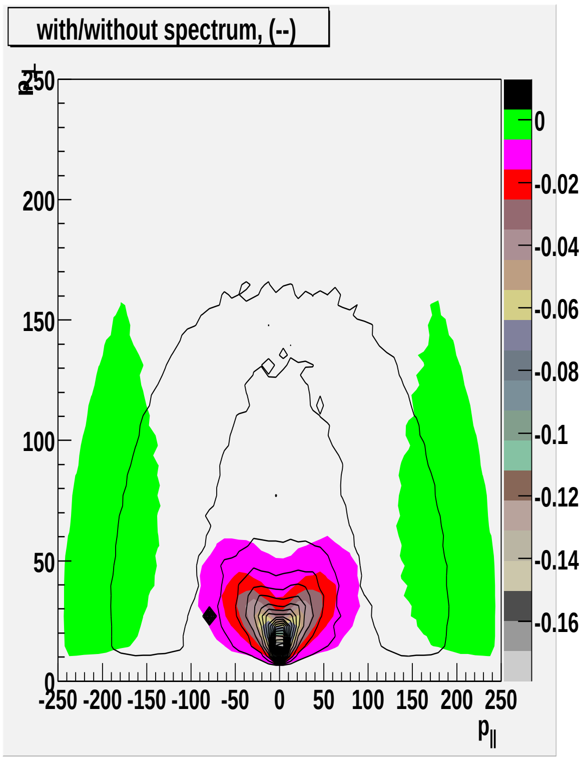


The charge asymmetry for the $+-$ initial state

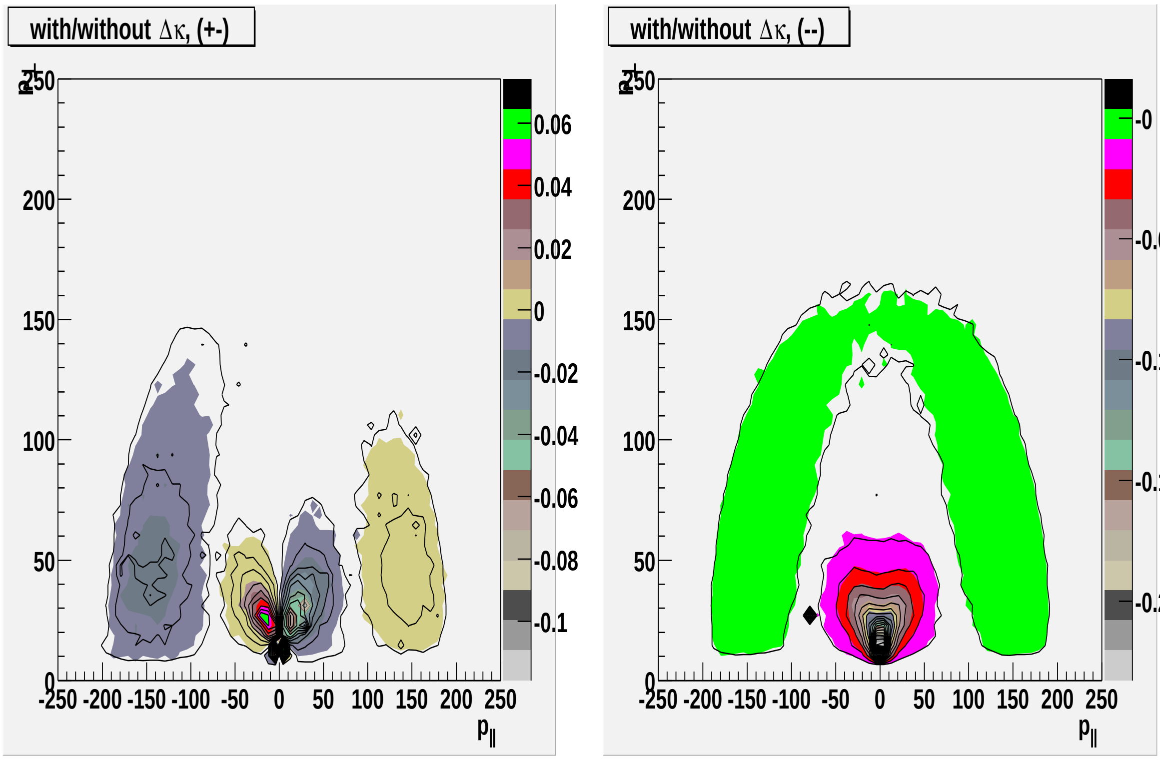
$$\frac{d^2\sigma}{dp_{+\ell}dp_{+\perp}} - \frac{d^2\sigma}{dp_{-\ell}dp_{-\perp}}$$

• The photons are nonmonochromatic. The energy spectra are known well for the high energy photons and will differ depending on detail of technology for low energy. Fortunately, the low energy photons are nonpolarized and don't contribute to asymmetry. Below I show effect of photon spectra. In color – with photon spectra. Lines without color – effect for monochromatic photons.



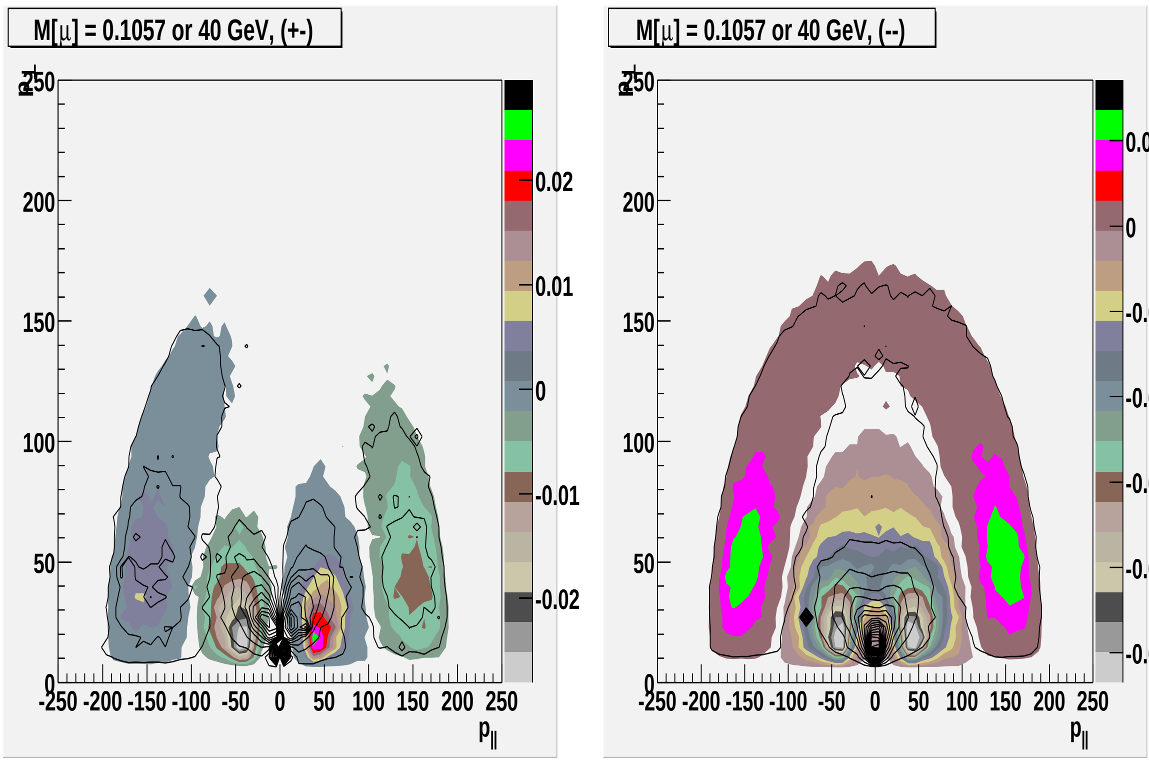


• The possible anomalous interactions of gauge bosons change form and value of asymmetry. Below we show the effect of anomalous magnetic momentum of W. In color – with $\Delta\varkappa = 0.1$. Lines without color – $\mathcal{SM}$ ($\Delta\varkappa = 0$) (with photon energy spectra).



• To mimic effect of heavy superparticles, etc. we consider also the case with very heavy "μ". The obtained charge asymmetry is compared with that for real muon ($M_\mu = 0.107$ GeV). In color – with $M_\mu = 40$ GeV, lines without color – for $M_\mu = 0.107$ GeV

(with photon energy spectra)



The calculations with other anomalies and sensitivity to New Physics effect are in progress.