

# New methods of distinguishing the associated $Z\gamma$ production

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**Abstract.** Indirect searches of beyond the Standard Model effects are discussed. The  $Z(\nu\bar{\nu})\gamma$  process is considered in this respect. The limiting factors of the separation of this process from the background one are studied phenomenologically. New potential selection methods are proposed to increase the signal to background ratio.

## 1 Introduction

After the discovery of the Higgs boson by the LHC experiments [1, 2], the main focus in the high energy physics was shifted to the extensive search of beyond the Standard Model physics (BSM) or so-called "new physics".

In general, there are two basic methods of such search. The first method, which is called *direct search*, is the kind of study, when one is looking for the new particles which are not predicted by the Standard Model (SM). The second method, called *indirect search*, is the study, when one is looking into the known processes with the highest possible precision to be able to find any small deviation caused by the new physics.

### 1.1 Direct searches

The direct searches are running by both ATLAS and CMS experiments and the most relevant mass limits are demonstrated in figure 1.

As a summary from these limits, it should be noticed that no new particles were observed and the limits are on the level of 3-5 TeV already. These limits will not be significantly improved without increase the collision energy, which is not foreseen in the near future.

### 1.2 Indirect searches

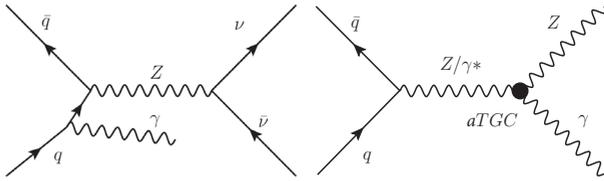
The indirect searches, where the new physics from the higher energy range slightly changes interactions of the known particles, are also in the focus of the experimental studies. In this type of searches, the significant gain could arise from the increase of luminosity, which is planned for the LHC.

Indirect searches is the hot topic in the fields of flavor physics (especially, b-physics), electroweak bosons interactions, top physics, etc. Theory predictions can also reach high level of precision for these sectors, as far as the techniques of perturbative calculations are improving intensively.

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**Figure 3.** Feynman diagrams of  $Z(\nu\bar{\nu})\gamma$  production: SM initial-state photon radiation (left) and an aTGC BSM vertex (right).

In the figure 3 one can see the Feynman diagrams for SM and BSM associated  $Z\gamma$  productions.

Neutral anomalous couplings can be described by the vertex functions formalism, where the coupling is described by eight parameters  $h_1^V-h_4^V$  (where  $V = Z, \gamma$ ) [6]. Non-zero values of such parameters lead to the excess in  $Z\gamma$  cross section at high energies. Current sensitivity of experiments to the  $Z\gamma\gamma/ZZ\gamma$  vertices become close to the order of SM loop corrections. The predicted order of this value is  $10^{-4} - 10^{-5}$  [7]. The loop contribution from BSM models, such as SUSY, is different. This fact can also provide constrains for the BSM models from the experimentally obtained limits.

## 2.2 Discussion on limiting factors

The latest public analyses for the considered final state are available in [8] for the ATLAS and in [9] for the CMS experiment.

One of the main limiting factors, which decrease the sensitivity of this final state, is the significant background contamination.

If one looks into selection criteria of the  $Z(\nu\bar{\nu})\gamma$  studies, it can be noticed that they has high level of similarity. Both experiments use quite high photon  $p_T$  threshold and high missing  $p_T$  requirement. Also both of the experiments are using charged lepton veto and the angular cut on  $\Delta\phi(\gamma, \vec{p}_T^{miss})$ . The ATLAS selection is a bit more advanced and has some additional constraints, such as a requirement of  $E_T^{miss}$  significance <sup>1</sup>.

The highest background contamination comes from the process of  $W\gamma$  associated production. It has two main sources:

- Lepton is not reconstructed or identified or it is out of the experimental acceptance;
- $W$  decays into  $\tau$  lepton mode, with subsequent  $\tau$  decay into hadrons.

So the main goal is to construct the criteria for the further suppression of this dominant background process.

## 2.3 Setup for the study

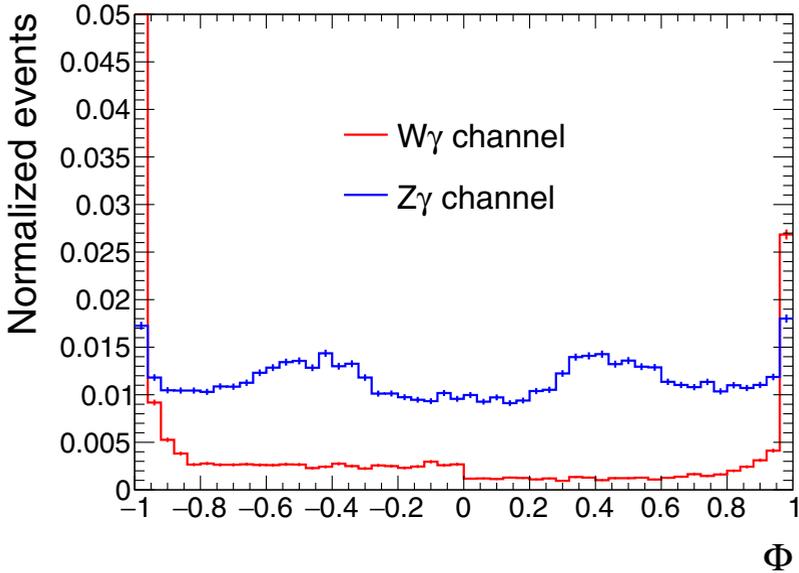
For the study of possible additional observables, which are sensitive to the differences between  $Z\gamma$  and  $W\gamma$  channels, one used the chain of Monte Carlo (MC) simulation, which consists of MG5\_aMC@NLO generator [10] for the initial hard-scattering processes, Pythia8 [11] for the modeling of the parton shower, hadronization and underlying event, and the Delphes framework [12] for the detector simulation and particle reconstruction.

## 2.4 New angular requirement

The  $W\gamma$  and  $Z\gamma$  background channels are very similar in terms of analysis. In this case, within the Signal Region (SR), only two four-vectors can be measured:  $p_T^{miss} = \{\vec{p}_T^{miss}, E_T^{miss}\}$  and

<sup>1</sup>  $E_T^{miss}$  significance =  $E_T^{miss} / \sqrt{\sum p_T^{jet} + E_T^\gamma}$

$p^\gamma = \{\vec{p}^\gamma, E^\gamma\}$ . Thus the set of variables that possibly could be used for the separation of  $W\gamma$  and  $Z\gamma$  channels is limited: the missing transverse energy and the energy of the photon, the missing transverse momentum and the photon's momentum, as well as the angles between different particles' momenta.



**Figure 4.** The distribution over the  $\cos(\widehat{\vec{p}^\gamma \vec{p}_T^{miss}})$  variable in the  $p_T^{miss}$  rest frame at the Monte Carlo generator level.

During the previous analyses, the variable used for the separation of these channels was the angle between the missing transverse momentum and the transverse momentum of the registered photon:  $\phi = \widehat{\vec{p}_T^{miss} \vec{p}_T^\gamma}$ . In this case, not all the information, available from the measurements, is used: the Z-axis projection of the photon momentum  $p_Z^\gamma$  is not involved. In order to include the missing  $p_Z^\gamma$  information, which possibly could increase the separation power, the new angular variable was suggested. This new variable  $\Phi$  defines as the cosine of the angle between the photon momentum  $\vec{p}^\gamma$  and the missing transverse momentum  $\vec{p}_T^{miss}$ :  $\Phi = \cos(\widehat{\vec{p}^\gamma \vec{p}_T^{miss}})$ . In this case  $\Phi$  is no more the flat angle in the transverse plane but the spatial angle between the two momenta. The preliminary results of Monte Carlo simulation corresponding to the  $\Phi$  variable in the  $p_T^{miss}$  rest frame are shown in figure 4. The generated statistics was 100k events for both  $W\gamma$  and  $Z\gamma$  channels.

Figure 4 demonstrates that  $\Phi$  variable has the separation potential - while for the  $Z\gamma$  channel events are distributed over the range of values relatively uniformly, in case of  $W\gamma$  channel almost all the events are located around borders ( $\Phi = \pm 1$ ). This property allows to apply an additional separation cut in the analysis, based on the value of  $\Phi$ .

### 2.5 Soft jets term requirement

The missing transverse energy can be calculated as the negative sum of all reconstructed particles energy deposit in the calorimeter [12]:

$$\vec{p}_T^{miss} = - \sum_i \vec{p}_T(i), \tag{1}$$

where the index  $i$  runs over the identified particles.

There is a difference in the  $\vec{p}_T^{miss}$  for these two processes in study:

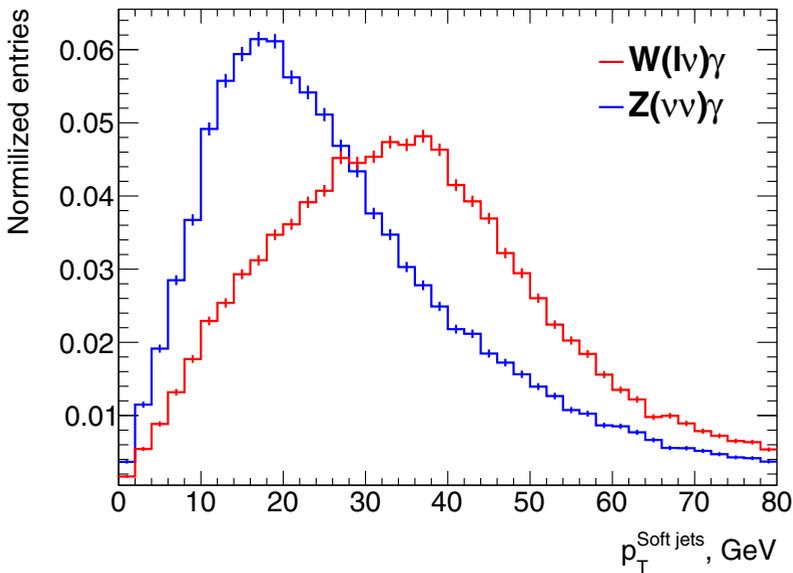
- For  $Z\gamma$  process the full momentum of  $Z$  is genuine missing transverse energy. It will not present in the equation 1.
- For  $W\gamma$  process the part from the charged lepton will leave a deposit in most of cases as a soft jet, which will be included in the equation 1.

Thus the missing transverse energy distribution should be slightly different. However the best separation power will give the soft jets term, which can be calculated as follows:

$$\vec{p}_T^{soft\ jets} = \vec{p}_T^{miss} - \sum_j \vec{p}_T^{hard\ particles}(j), \tag{2}$$

where the index  $j$  runs over the hard objects: identified photons, leptons and jets with  $p_T > 10$  GeV.

It will include just soft jets contributions. This observable is shown for  $W(l\nu)\gamma$  and  $Z(\nu\bar{\nu})\gamma$  in figure 5.



**Figure 5.** Distributions for sum of soft jets  $p_T$  (soft jets term) in the case of  $W(l\nu)\gamma$  and  $Z(\nu\bar{\nu})\gamma$  processes.

Indeed the shapes are quite different, which shows a good separation potential.

### 3 Conclusions

Indirect “new physics” searches are now playing the leading role in the high energy physics. Anomalous couplings searches are one of the most perspective topics.

The  $Z\gamma$  final state (with  $Z$  decay to neutrino-antineutrino pair) is sensitive to the neutral anomalous couplings. The phase space for its measurement can be optimized further.

Two new observables with good separation potential of the dominant  $W\gamma$  background were suggested:

- $\Phi = \cos\left(\vec{p}^\gamma \widehat{p}_T^{miss}\right)$ ;
- Soft jets term  $p_T^{soft\ jets}$ .

The optimization is still ongoing, but the results of such optimisation can already be used in the experimental studies, like fiducial volume definition, additional machine learning discriminants, etc.

### 4 Acknowledgements

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