Z Boson Pair Exclusive Production from Two Photon Exchange with Anomalous Gauge Boson Couplings in p p Collisions at 13 TeV

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A simulation for the existence of particles and couplings, that are not predicted in the Standard Model (SM), can be performed by evaluating the contributions of anomalous photon-gauge boson couplings to W and Z pair production in proton-proton collisions at the LHC. In this work, we present our preliminary results for Z pair exclusive production from two-photon exchange with anomalous gauge boson quartic couplings, by considering a 1 TeV scale for new physical effects. We consider some values for the integrated luminosity up to 100 fb^{-1} at center-of-mass energy of 13 TeV. We calculate the total cross section for the exclusive process and we present the resulting four lepton invariant mass distribution. Finally we present an outlook for the present analysis.

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1. Introduction

At the Large Hadron Collider (LHC), pp collisions produce a significant number of high-energy quasi-real photons. Hence, LHC can be somehow considered as a high-energy photon-photon or photon-proton collider, allowing for a standard luminosity calibration. In this conjecture, the small effective luminosity is compensated by the knowledge of the initial condition associated with a clear experimental signature of the produced particles. In particular the presence of very forward scattered protons, to be explored by the new dedicated detectors such as the CMS-TOTEM Precision Proton Spectrometer (CT-PPS) at CMS [1], helps the identification of the relevant signal. Another important aspect is related to the simulation of new physical effects, by introducing anomalous couplings of photons with gauge bosons [2].

Anomalous couplings can be introduced by building an effective Lagrangian which models the low energy behavior of possible extensions of the SM. Here we introduce the so-called genuine quartic anomalous couplings by adding new interaction terms via effective dimension-6 operators conserving local $U(1)_{em}$ and custodial $SU(2)_c$ symmetries.

We start by discussing the Equivalent Photon Approximation (EPA) which lies on the hypothesis of factorization of the two-photon cross section from the two photon fluxes [3]. Next we present the effective Lagrangian and the procedure to calculate the matrix elements, as well as to simulate the production cross section using the FPMC [4] events generator. Our results are shown for Z pair production with a brief discussion on background contributions.

2. Equivalent Photon Approximation

The exclusive production of gauge boson pairs is a photon-induced process that happens when each incoming proton emits one low virtuality photon ($Q^2 < 2$ GeV^2) that interacts producing an object X characterized by the available two-photon energy $W_{\gamma\gamma}$. Since the average photon virtualities are very low, one can safely treat all such processes as quasi-real photon interactions [5].

The factorization of the amplitude of a given process as the product of a photon exchange part by the photon interaction part allows us to use the Equivalent Photon Approximation (EPA) to describe Z pair production from two-photon exchange. For ZZ quartic interactions with two photons, that are absent in the SM Lagrangian, we introduce an effective Lagrangian with two anomalous couplings a_0^Z and a_C^Z and an energy scale of new physics, $\Lambda \sim 1$ TeV [6].

$$\mathscr{L}_6^0 = \frac{e^2}{16\cos^2\theta_W}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha + \frac{e^2}{16\cos^2\theta_W}\frac{a_C^Z}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}Z^\alpha Z_\beta$$

Let us recall that an exclusive process is characterized by an empty region of pseudo-rapidity that occurs when the forward protons are detected apart from the decay particles of the massive produced object [7]. In particular, for the two-photon exchange in pp collisions considered here is a pair of Zs decaying into leptons. The expected experimental topology corresponding to the signal is characterized by three aspects. First the production of very forward protons that remain intact, second the presence of very few particles in the central region and finally the production of leptons with high transverse momentum.

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3. Procedure and Results

The present analysis of *Z* pair production from two photon interaction requires photon-gauge boson anomalous coupling, because the quartic coupling $\gamma\gamma ZZ$ is not present in the SM Lagrangian. For the signal we calculate two pair of e^+e^- or $\mu^+\mu^-$ or one pair of e^+e^- and one pair of $\mu^+\mu^-$ produced by two photons coupled with two Zs as given by $\mathscr{L}^{0,C}$.

We employ the *Forward Physics Monte Carlo* (FPMC) package for event generation, where we apply minimal cuts for each lepton transverse momentum $p_T > 10$ GeV and $|\eta| < 2.5$ for the lepton pseudo-rapidity. We perform the selection of the final state by using the HepMC event record format [8]. Then, we write a macro in the ROOT framework [9] to choose the highest transverse momentum leptons to produce the final observables and distributions.

We consider the proton momentum lost in the interval $0.015 < \xi_i < 0.17$, $i = 1, 2$ for the signal, where we select one lepton pair with the highest transverse momentum such that their momenta combination corresponds to an on-shell *Z*; these selected pair do not participate in the selection of the other pair with combined momenta corresponding to $M_Z \pm 10$ GeV. We define the central mass by $M_X^2 = \xi_1 \xi_2 s$, for $\sqrt{s} = 13$ TeV and we present the contribution of anomalous photon-gauge boson couplings for *Z* pair production.

The results of four lepton mass distribution corresponding to a muon-anti-muon pair and a electron-positron pair, when all mentioned cuts are implemented is shown in the left panel of figure 1; the $\gamma\gamma$ central mass is shown in the right side of same figure.
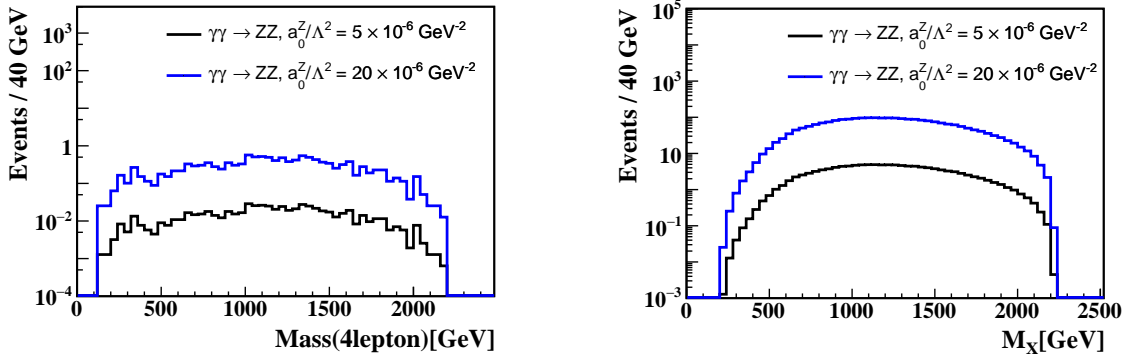

Figure 1: *Left:* The four lepton mass distributions. *Right:* Central mass distributions. These results are in pp collision at 13 TeV for 100 fb^{-1}, for two values of photon-gauge boson anomalous coupling.

In addition we calculate the ratio R$_{sign}$ of the expected number of four leptons satisfying the cuts N_{signal} and the total number of double pair produced. We summarize this analysis with a table that shows the expected number N_{signal} of two pairs of leptons in the four lepton mass distribution, and the value of *R*.

	L=30	L= 50	L=100		L=30	L=50	L=100
N_{signal}	0.22	0.33	0.67	N_{signal}	3.9	6.6	13.1
R_{sign}	0.98	1.03	1.4	R_{sign}	17	20	27

Table 1: Number signal events and the ratio *R* for three values of the integrated luminosity given in fb^{-1}. *Left* for $a_0^Z/\Lambda = 5 \times 10^{-6}$ GeV^{-2}. *Right* for $a_0^Z/\Lambda = 20 \times 10^{-6}$ GeV^{-2}.
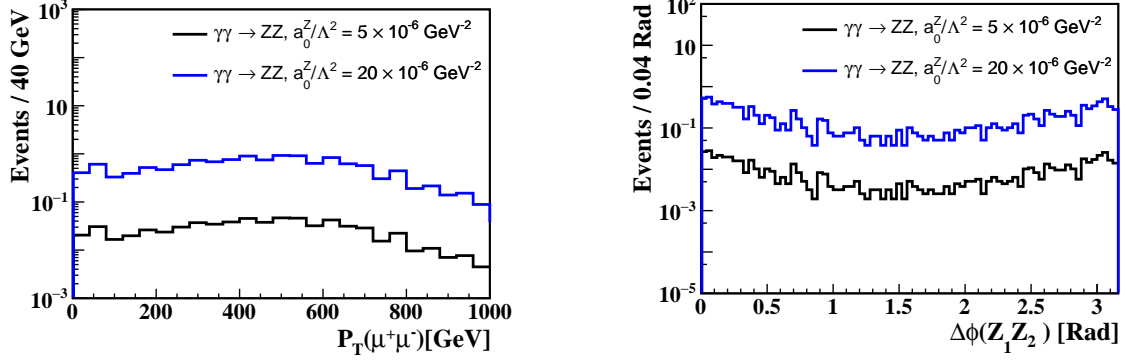
Figure 2: *Left:* Transverse momentum distributions for a muon-anti-muon pair in pp collision at 13 TeV for 100 fb^{-1}. *Right:* Angular azimutal deviation of the two lepton pairs.

4. Comments and Perspectives

We analyze the exclusive production of a pair of Zs from two-photon exchange in *pp* collisions at the LHC for $\sqrt{s} = 13$ TeV for integrated luminosity up to 100 fb^{-1}. We introduce two anomalous coupling parameter in the Lagrangian $\mathcal{L}_6^{0,C}$ to show that the presence of anomalous couplings can be identified from the four lepton mass distributions.

These are preliminary results, to be complemented by a deep evaluation of backgrounds processes. On the other hand, we intend to use a specific model, with additional gauge bosons to the SM ones, to compare its result with those following from effective anomalous couplings.

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