

Photon Physics at LHC

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Experimental prospects for studying high-energy photon-photon and photon-proton interactions at the LHC are discussed. Assuming a typical LHC multipurpose detector, various signals and their irreducible backgrounds are presented after applying acceptance cuts. Selection strategies based on photon interaction tagging techniques are presented. Prospects are discussed for the Higgs boson search, detection of SUSY particles and of anomalous quartic gauge couplings, as well as for the top quark physics.

1 Introduction

A significant fraction of pp collisions at the LHC will involve (quasi-real) photon interactions, at center-of-mass (c.m.s) energies well beyond the electroweak energy scale. Hence, the LHC can to some extent be considered as a high-energy photon-photon or photon-proton collider.

The equivalent photon approximation (EPA) can be successfully used to describe the majority of processes involving photon exchange, provided that the amplitude of a given process can be factorised into the photon exchange and interaction parts [2]. The photon-photon and photon-proton cross sections, $\sigma_{\gamma\gamma}$ and $\sigma_{\gamma p}$, must be convoluted with the photon spectra $dN(E_\gamma, Q^2, E)$ to obtain the pp cross sections. This paper considers the low pile-up conditions available at start-up and focuses on the irreducible backgrounds to the presented analyses. Deeper studies involving inclusive background will be the object of later communications.

2 Photon-Photon Interactions

Many $\gamma\gamma$ cross sections at the LHC are sufficiently large to yield interesting measurements (see figure 1). In particular, the expected high statistics for exclusive W pair production should allow precise measurement of the $\gamma\gamma WW$ quartic couplings. The existence of new massive charged particles can also be probed using the two-photon pair production. The particular case of super-symmetric pairs is considered here. Moreover, the two-photon exclusive production of muon pairs will be an excellent luminosity monitoring tool [3].

Two-photon exclusive production of muon pairs at the LHC has a well known cross section, and requires very small hadronic corrections. Small theoretical uncertainties and a

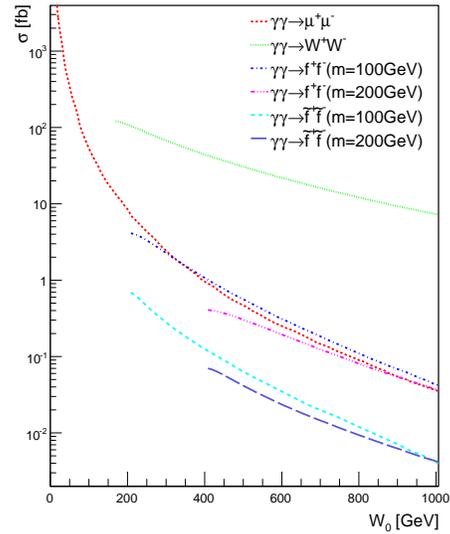


Figure 1: Cross sections for various $\gamma\gamma$ processes as a function of the minimal photon-photon c.m.s. energy W_0 . No cut is applied

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large cross section ($\sigma = 72.5$ pb at LHC energies) makes it a perfect candidate for the LHC absolute luminosity measurement [3]. The selection procedure is very simple: two opposite charge muons within the central detector acceptance ($|\eta| < 2.5$), with transverse momenta above some low thresholds ($p_T^\mu > 3$ or 10 GeV). Requiring one proton tagged would yield 150 muon pairs detected in a 12 h run at the average luminosity of 5×10^{32} cm⁻²s⁻¹, allowing run by run calibration of the very forward detectors (VFD).

Two-photon production of W boson pairs provides a unique opportunity to investigate anomalous gauge boson couplings, in particular the quartic gauge couplings (QGC) $\gamma\gamma WW$. For 1 fb⁻¹, the obtained limits of 0.49, 1.84, 0.54 and 2.02×10^{-6} for $|a_0^Z/\Lambda^2|$, $|a_C^Z/\Lambda^2|$, $|a_0^W/\Lambda^2|$, $|a_C^W/\Lambda^2|$, respectively, are about 10,000 times better than the best limits established at LEP2 [4] clearly showing large and unique potential of such studies at the LHC. The unique signature with large lepton acoplanarity (and large missing transverse momentum) drastically reduces the backgrounds.

The interest in the two-photon exclusive production of pairs of new charged particles is threefold: it provides a new, complementary and very simple production mechanism; constraints on the masses of new particles could be obtained using double VFD tagged events; finally, final states involving super-symmetric particles are usually produced without cascade decays. The fully leptonic final state consists of two acoplanar charged leptons and large missing energy has low background. The corresponding Feynman diagrams are shown at figure 2.

The only irreducible background for this type of processes is the exclusive W pair production. Indeed, direct lepton pairs $pp(\gamma\gamma \rightarrow \ell^+\ell^-)pp$ can be suppressed using large acoplanarity cuts. Discovery of super-symmetry via $\gamma\gamma$ interaction is *a priori* difficult because of production cross sections smaller than 1 fb before acceptance cuts. However, the measured energy of the two scattered protons in VFDs could allow for the distinction between various contributions to the photon-photon invariant mass $W_{\gamma\gamma}$ [5].

3 Photon-Proton Interactions

The high luminosity and the high c.m.s. energy of photo-production processes at LHC offer interesting possibilities for the study of electroweak interaction and for searches beyond the Standard Model (BSM) up to the TeV scale. The cross sections for various electroweak and BSM reactions together with their irreducible (Standard Model) background processes are shown in figure 3.

Several processes have been studied in detail to illustrate the discovery potential of photo-production at LHC. In contrast to photon-photon reactions, the photo-production processes involve topologies with hard jets in the final state. The effect of jet algorithms and the efficiency of event selection was taken into account using a fast simulation of a typical multipurpose LHC detector response [6].

The associated WH photo-production cross section reaches 23 fb for a 115 GeV Higgs boson and 17.5 fb for a 170 GeV Higgs boson. It represents more than 2% of the total inclusive WH production at the LHC.

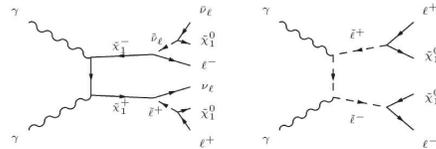


Figure 2: Most relevant Feynman diagrams for SUSY pair production with leptons in the final state. Left: chargino decay in a charged/neutral scalar and a neutral/charged fermion; Right: slepton decay.

When the decay branching ratio of the Higgs boson into a W pair becomes dominant, the same sign lepton signature coming from leptonic decays of two out of the three produced W seems promising. It has a signal to noise ratio of about one, which is unique at LHC. An integrated luminosity of a few tens of inverse femtobarns could directly reveal the HWW gauge coupling.

The Hbb coupling, very challenging to assess in parton-parton processes, could be probed for a light Higgs boson if sufficient integrated luminosity without pile-up can be collected.

Photo-production of single top is dominated by t-channel amplitudes when the top quark is produced in association with a W boson. In contrast to proton-proton deep inelastic scattering where the ratio of Wt associated production cross section to the sum of all top production cross sections is only about 5%, it is about 10 times higher in photo-production as illustrated in Table 1. This provides a unique opportunity to study this reaction at the start phase of LHC.

Cross sections after the application of acceptance cuts are shown in table 2. For the signal, a value of 0.1 was chosen for $k_{tu\gamma}$ while $k_{tc\gamma}$ was set at zero. The resolved $\gamma p \rightarrow Wj\gamma$ is negligible.

Cross section [fb]	$\ell b j j$	$\ell \ell b$
σ Wt	440	103.7
σ_{acc}	34.1	8.69
Irreducible processes		
σ_{acc} $t\bar{t}$	46.37	2.80
$Wjjj$	15.61	-
$Wb\bar{b}q'$	1.01	-
W^+W^-q'	-	0.18
σ_{acc} total	62.99	2.99

Table 1: Cross sections for two Wt induced final states before and after acceptance cuts together with the cross sections of irreducible background processes after acceptance cuts.

Conventionally taken as the top mass. The best upper limit on $k_{tu\gamma}$ is around 0.14, depending on the top mass [10] while the anomalous coupling $k_{tc\gamma}$ has not been probed yet.

The final state is composed of a b -jet and a W boson. The studied topology is therefore ℓb . Main irreducible background processes come from γp interactions producing a W boson and a jet mistagged as a b -jet.

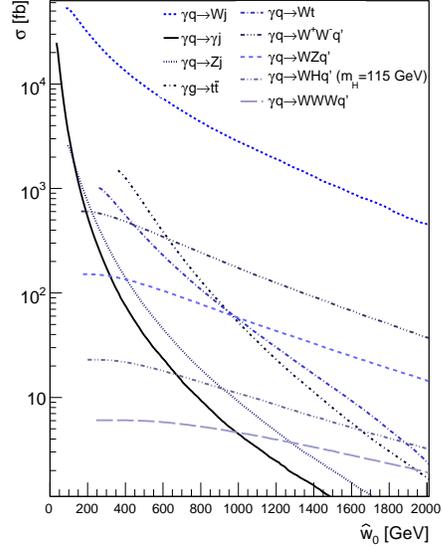


Figure 3: Cross sections for $pp(\gamma q/g \rightarrow X)pY$ processes as a function of the minimal photon-parton c.m.s. energy \hat{W}_0 .

While the overall photoproduction of top quark is sensitive to the, yet unmeasured, top quark electrical charge, the Wt associated photoproduction amplitudes are all proportional to the CKM matrix element $|V_{tb}|$. Preliminary studies show that the di-leptonic channel could be competitive with the inclusive channel as detailed in [7]. Single top photoproduction could reveal phenomena beyond the Standard Model, and in particular Flavour Changing Neutral Currents (FCNC)[8]. The effective Lagrangian for this anomalous coupling can be written as [9] :

$$L = iee_t \bar{t} \frac{\sigma_{\mu\nu} q^\nu}{\Lambda} k_{tu\gamma} u A^\mu + iee_t \bar{t} \frac{\sigma_{\mu\nu} q^\nu}{\Lambda} k_{tc\gamma} c A^\mu + h.c.,$$

where $\sigma^{\mu\nu}$ is defined as $(\gamma^\mu \gamma^\nu - \gamma^\nu \gamma^\mu)/2$, q^ν being the photon 4-vector and Λ an arbitrary scale, con-

The present selection together with the assumption that no other background contribution will interfere, would lead to the expectation of a five sigma discovery just below 1 fb^{-1} of integrated luminosity. The extracted limits on the anomalous couplings $k_{tu\gamma}$ and $k_{tc\gamma}$ are reported in table 3.

4 Conclusion

A survey of high energy $\gamma\gamma$ and γp interactions at LHC has been presented. The large cross sections show the potential of the study of massive electroweakly interacting particles in a complementary way to the usual, parton-parton processes, at the very start of LHC.

Photon-photon interactions will allow precise luminosity monitoring while large integrated luminosity studies open complementary ways to search for SUSY particles.

At high luminosity, the efficient selection of photon induced processes is conditioned by the capacity of experiments to tag forward protons by means of dedicated forward detectors. In this context, R&D programs such as FP420[11] and other developments related to the instrumentation of forward regions of CMS and ATLAS experiments, are particularly important.

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Cross section [fb]	lb
σ_{t}	769.0
σ_{acc}	144.0
Irreducible backgrounds	
$\sigma_{acc} Wj$	56.2
Wc	82.8
σ_{acc} total	139.0

Table 2: Cross sections for one anomalous top induced final state ($k_{tu\gamma} = 0.1$, $k_{tc\gamma} = 0$) before and after requiring 1 lepton and 1 b-jet within $|\eta| < 2.5$ together with the cross sections of irreducible background processes after these acceptance cuts.

Coupling	Limits	
	L = 1 fb^{-1}	L = 10 fb^{-1}
$k_{tu\gamma}$	0.043	0.024
$k_{tc\gamma}$	0.074	0.042

Table 3: Expected limits for anomalous couplings at 95% CL for two values of integrated luminosities.