PROCEEDINGS OF SCIENCE

High energy $\gamma\gamma$ interactions at the LHeC

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The future Large Hadron-electron Collider (LHeC) will operate at a center-of-mass energy of 1.2 TeV, delivering an integrated electron-proton luminosity of approximately 1 ab^{-1}. The high luminosity and clean experimental environment at LHeC promise unique research opportunities, requiring a comprehensive survey of high-energy $\gamma\gamma$ interactions up to center-of-mass energies of 1 TeV. In this contribution, the potential for scientific discovery is briefly assessed by discussing the $\gamma\gamma$ processes, particularly the two-photon exclusive production of supersymmetric particles.

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1. Introduction

The proposed Large Hadron-electron Collider (LHeC) at CERN opens fascinating new areas of research. This article focuses on an exciting aspect of this facility: the unique studies of high-energy $\gamma\gamma$ interactions. Initially set to operate alongside the high-luminosity mode of the LHC (HL-LHC), the LHeC will achieve a high center-of-mass energy of $\sqrt{s} = 1.2$ TeV for electron-proton collisions, with beam energies of $E_e = 50$ GeV for electrons and $E_\text{p} = 7$ TeV for protons [1]. These conditions could push the energies of photon-photon collisions beyond the threshold for electroweak interactions, potentially reaching up to the TeV-scale. The LHeC impressive nominal luminosity, exceeding 10^{34} cm^{-2}s^{-1}, with a foreseen total integrated luminosity of approximately 1 ab^{-1}, will enable precision tests of the Standard Model (SM) and the exploration of any signature of New Physics (NP) beyond the SM [1].

From an experimental perspective, the LHeC will offer favorable conditions, such as very low event pileup compared to HL-LHC, powerful exclusivity selections covering a wide range of rapidity, the absence of re-scattering effects, and a cleaner experimental environment.

As a theoretical framework to calculate the cross-sections for two-photon interactions in electron-proton collisions, the *Equivalent Photon Approximation* (EPA) [2] can be employed. In this approach, the electron-proton level cross-section for a given photon-photon interaction can be accurately determined by convoluting the equivalent photon fluxes from electrons and protons with the corresponding photon-photon level cross-section [2–4]. In extension, the convolution of the two photon fluxes provides the photon-photon luminosity spectrum $S_{\gamma\gamma}$, reflecting the intensity of the effective photon-photon collisions. In Fig. 2, the calculated elastic and inelastic luminosity spectrum $S_{\gamma\gamma}$ at the LHeC are presented for $Q^2_\text{e} < 10^5$ GeV^2 and $Q^2_\text{p} < 10$ GeV^2 assuming an upper limit of $M_N < 10$ GeV for the diffractive mass of the proton beam in the inelastic photon emission case.

2. Two-photon exclusive production of supersymmetric pairs

The LHeC will provide a unique laboratory to study a wide range of photon-photon processes with high significance, including $\gamma\gamma \to \gamma\gamma$, $\gamma\gamma \to \ell^+\ell^-$ ($\ell = e, \mu, \tau$), $\gamma\gamma \to ZZ$, $\gamma\gamma \to WW$, $\gamma\gamma \to H$, as well as the $\gamma\gamma$ production of a pair of charged supersymmetric particles. In this contribution, however, we limit ourselves to the exclusive two-photon production of higgsinos, supersymmetric partners of the Higgs field carrier, as pictured in Fig. 1.

Two-photon collisions allow for detailed studies of the production of particles beyond the Standard Model (SM) with high precision [5, 6]. In particular, investigating the production of non-strongly interacting supersymmetric (SUSY) particles, specifically sleptons and higgsinos, through photon-photon ($\gamma\gamma$) collisions at the LHeC holds considerable interest. The anticipated high luminosity at the LHeC, coupled with its clean experimental conditions, offers a unique opportunity to study this process with an improved statistical significance and reduced sources of background. In addition, in two-photon processes, production and decay mechanisms are generally simple. Leptonic final states [7] can also be considered, resulting in much cleaner event topologies at the LHeC.

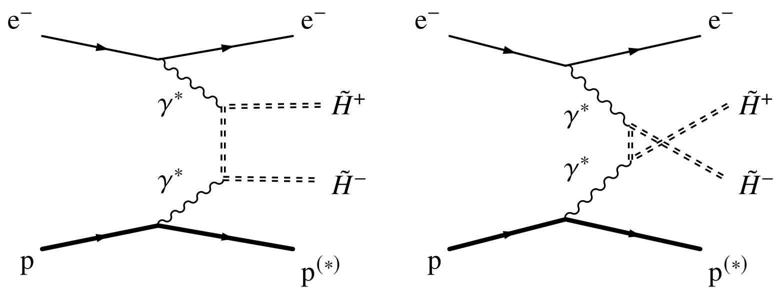

Figure 1: Diagram for the t and u-channel ep $\to$ e$(\gamma\gamma \to \tilde{H}^{+}\tilde{H}^{-})p^{(*)}$ processes studied as a probe for two-photon production of supersymmetry in this report.

Having at hand the two-photon luminosity spectrum $S_{\gamma\gamma}$, and considering the fact that higgsinos are coupled to photons as standard fermions of spin $\frac{1}{2}$ [4, 8], one can calculate the production cross section at LHeC using EPA [2, 4]. The differential total cross-section, as a function of minimal photon-photon center-of-mass energy (W_0) is shown in Fig. 2 for a given higgsino mass $M_{\tilde{H}} = 100$ GeV. All integrated values quoted here assume a kinematic range $Q^2_{\mathrm{e}} < 10^5$ GeV^2 and $Q^2_{\mathrm{p}} < 10$ GeV^2 for the electron/proton vertex, with an additional constraint on the diffractive system mass $M_N < 10$ GeV for the inelastic case.

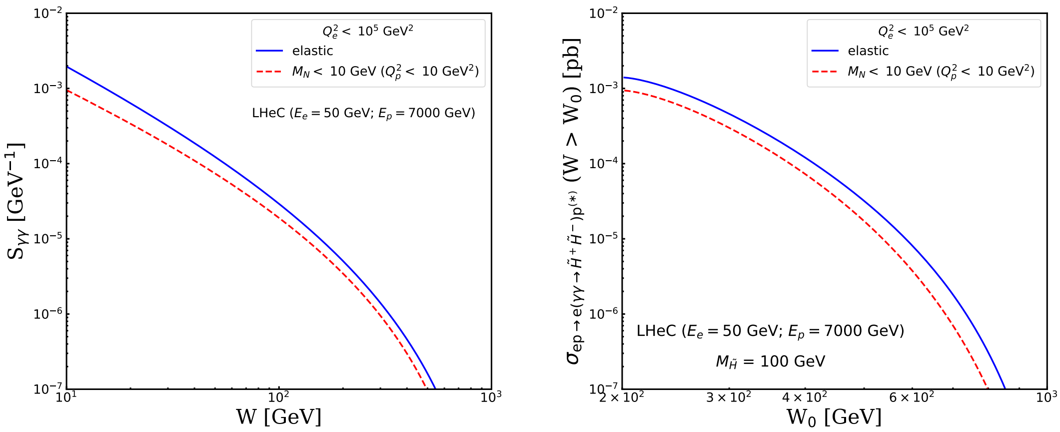

Figure 2: (left) Elastic and inelastic luminosity spectra $S_{\gamma\gamma}$ at the LHeC; (right) integrated higgsinos production cross sections, as a function of the minimal $\gamma\gamma$ center-of-mass energy, W_0, through the elastic and inelastic production with $M_N < 10$ GeV. Both cross-sections values are calculated for a given $M_{\tilde{H}} = 100$ GeV.

As detailed in Table 1, cross-section values calculated using EPA at minimum two-photon invariant mass $W_0 = 200$ GeV are in good agreement with those obtained using two Monte Carlo event generators: Grape [9], and the LPAIR process [10] implemented in CepGen [11]. For the inelastic part of these results, photon emission from proton is modelled with input from the updated F_2 and F_L structure functions parameterisation `ALLM97` [12].

However, it should be noted that the calculation of LPAIR is based on the diagrams of the two-photon Bethe-Heitler (BH) process only, dominating a large fraction of the available phase space. In the high mass region, an additional contribution arising from Z^0 exchange is modelled in

Table 1: Generator-level cross-sections for a minimum two-photon invariant mass $W_0 = 200$ GeV for the $\gamma\gamma \rightarrow \tilde{H}^+\tilde{H}^-$ process using the EPA, and CepGen (with the LPAIR process)/Grape event generators. Theoretical uncertainties quoted in parentheses are statistical only.

Generator	$\sigma_{\text{fid}}^{\text{el}}$ (fb)	$\sigma_{\text{fid}}^{\text{inel}}$ (fb)
EPA	1.396	0.937
LPAIR (CepGen)	1.274(1)	0.883(1)
Grape (BH)	1.301(1)	0.856(3)
Grape (BH+ISR)	1.356(2)	0.907(4)

Grape, contrarily to the bare LPAIR process. Furthermore, Grape also models the effects of the initial state radiation (ISR).

Given the low magnitude of cross sections for the range of kinematics probed, very large integrated luminosity is required, which will be available at the LHeC as a photon-photon collider. Additionally, the high-resolution detectors and the high invariant mass of the two-photon system at the LHeC, well-defined initial states, and the distinct signatures of these exclusive processes in which result in low backgrounds, potentially allow for precise measurements to be carried out.

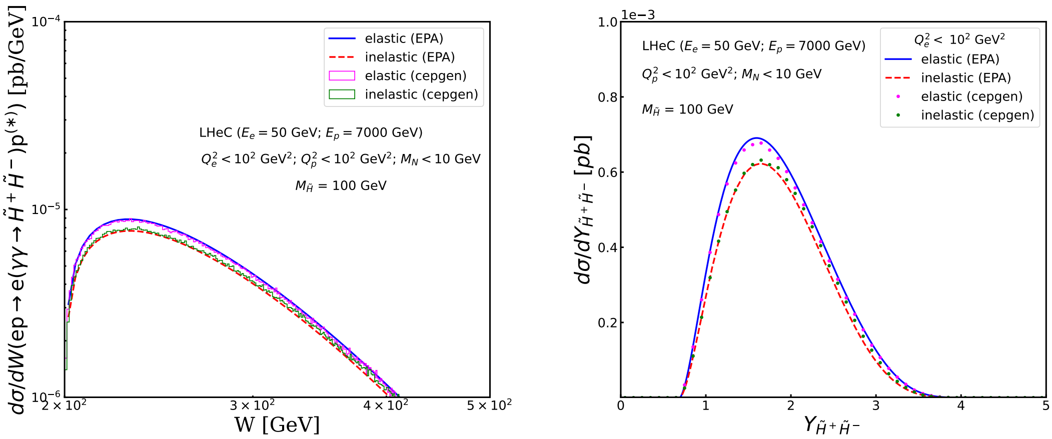

Figure 3: (left) The differential cross section $d\sigma/dW$ (in pb/GeV) as a function of the photon-photon center-of-mass energy W; and (right) the differential cross section $d\sigma/dY_{\tilde{H}^+\tilde{H}^-}$ (in pb) as a function of the higgsinos rapidity $Y_{\tilde{H}^+\tilde{H}^-}$.

To provide further weight to the discussion above, distributions for the differential cross sections $d\sigma/dW$ (expressed in pb/GeV) and $d\sigma/dY_{\tilde{H}^+\tilde{H}^-}$ (in pb) calculated using the EPA are presented in Fig. 3 and compared with those of the CepGen implementation of the LPAIR process. All distributions are shown for an arbitrary $M_{\tilde{H}} = 100$ GeV, both for elastic and inelastic photon emission cases. For the latter, the diffractive system mass is constrained to the upper value $M_N < 10$ GeV.

Upper limits for photon virtualities are also introduced to ensure the numerical convergence of the EPA convolution of photon fluxes: $Q^2_{\rm e,p} < 10^2$ GeV^2. As depicted in Fig. 3, EPA calculations for both elastic and inelastic processes agree well with LPAIR for the given definition of kinematics constraints. Despite the small-order corrections mentioned above, the bare EPA provides a very good approximation for the estimation of high-mass exclusive two-photon production cross-sections in electron-proton collisions, for a broad kinematic range typically accessible at LHeC energies.

The off-centering of the central system rapidity distribution reported in the rightmost part of Fig. 3 for the asymmetric ep kinematics mode is well covered by the optimised acceptance of LHeC detector geometry described in [13].

3. Summary and Conclusions

The future Large Hadron Electron Collider promises exciting opportunities for in-depth studies of high-energy photon-photon interactions. To fully explore the scientific potential of $\gamma\gamma$ physics at the LHeC, comprehensive surveys on efficient signal detection, as well as extensive investigations into the associated detector effects and requirements, are essential. In this paper, the $\gamma\gamma$ production of a higgsino pair at the LHeC is addressed as a case study. The calculated cross-section for higgsinos production is presented, and the compatibility of the EPA with available Monte Carlo generators is briefly discussed. It is expected that two-photon fusion processes can achieve sufficient rates at the LHeC to effectively search for SUSY particles and other signatures of New Physics.

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