Two-photon mechanism production of the Higgs boson, SUSY particles, hadrons and lepton pairs in eA Collisions at HERA

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Abstract: We present prospects for the study of a light neutral Higgs boson, SUSY-particle, hadrons and leptons production in the two-photon coherent eA collisions.

1 Introduction

Particle production in the two-photon processes in lepton-lepton, hadron-hadron and nucleus-nucleus collisions has been already discussed in the literature [1]-[5]. One of the goals of the present analysis is to study the discovery potential of electron-nucleus collisions at HERA in the case of coherent electromagnetic particle production. Preliminary results were presented in [6].

Requirement of coherency implies that the collision is quasi-elastic, the impact parameter b is larger than the nuclear radius and the nuclear charge acts as a whole. For such collisions the hadronic background from $\gamma^* q$ and $\gamma^* g$ (direct and resolved) subprocesses will be absent offering a better experimental environment for studying new particle production.

Due to the large charge Z of heavy ion and the strong contraction of the electromagnetic fields in a high-energy collision we expect in such an electron-nucleus interaction a large particle production rate by the two-photon fusion mechanism. It turns out that the cross sections, which is scaled with Z^2, are comparable or even large than the total cross sections expected in e^+e^- , ep and pp collisions of the same incident energy per particle.

An important characteristic of eA collider is its discovery range: how heavy produced particles can be and how large will be production cross sections for them. In the equivalent photon approximation the invariant mass squared of the two-photon system, denoted by W^2, is fixed by the photon energies ω_e and ω_A. As it well known [4], [5] that the time duration of the electromagnetic pulse, produced by a charge moving with a relativistic γ factor, corresponds to field frequencies of $\omega \leq \gamma/b$. In the case of a heavy-ion beam the largest photon energy is $\omega_A \simeq \gamma_A/R_A$ although for photons emerged from an electron beam the photon energy can be close to the electron energy $\omega_e \leq E_e$. Thus the discovery range of the eA HERA collider for coherent processes extends to masses:

$$W \approx (4\omega_e\omega_A)^{1/2} \leq \left(\frac{4\,E_e E_p}{m_p R_A}\right)^{1/2} . \tag{1}$$

This means the invariant mass values accessible at HERA energies are up to 86 GeV, 71 GeV and 54 GeV for eC, eCa and ePb collisions, respectively.

The paper is organized as follows: In the next section we compare the discovery ranges of eA (HERA), e^+e^- (LEP2) and ep (HERA) colliders using the two-photon luminosity function . In Sect.3, we evaluate cross sections for coherent production of lepton and slepton pairs (e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$, $\tilde{l}^+\tilde{l}^-$), charged pion pair, pseudoscalar ($J^C = 0^+$) resonances and 2HDM light Higgs boson. Conclusion is given in the last section.

2 Two-photon luminosity function

The equivalent photon approximation [1], [2], [7] allows to express the cross section for the production of a final state with the effective mass W in two photon collision as a product:

$$d\sigma_{eA} = \sigma_{\gamma\gamma} \cdot \frac{dL_{\gamma\gamma}}{dW} dW, \qquad (2)$$

where the cross section $\sigma_{\gamma\gamma}$ describes the $\gamma\gamma \to f$ transition for real non-polarized photon and a differential two-photon luminosity function (TPL) $dL_{\gamma\gamma}/dW$ is introduced[1]. Results presented here were obtained with use a particular form of $dL_{\gamma\gamma}/dW$ [6] derived for untagged scattered electron and nucleus

$$\frac{dL_{\gamma\gamma}}{dW} = \frac{2Z_A^2\alpha^2}{\pi} \frac{f(t^*)}{W} ln\left(\frac{s_{eA}}{4m_e^2}\right), \quad f(t^*) = (\ln t^* + \frac{\sqrt{3}}{2})^2 + (t^* - 4)^2 - 3 \qquad (3)$$

with $t^* = \frac{R_A W^2}{2\gamma_A\sqrt{s_{eA}}}$. Eq. (3) is valid in the leading logarithm approximation.

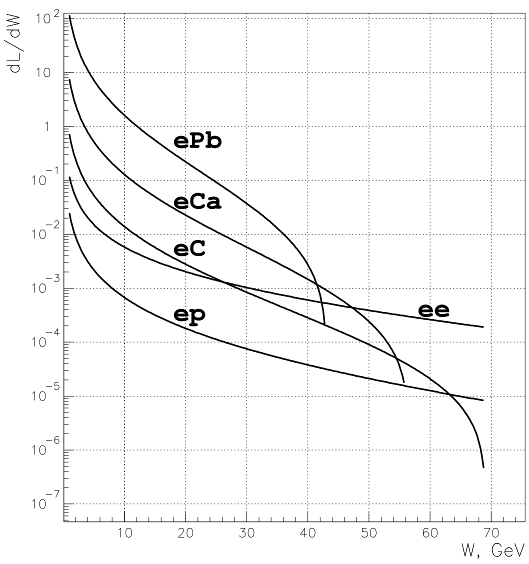

Figure 1: *Spectra of the two-photon luminosity function for e^+e^- (LEP, 200 GeV), ep(HERA, 300 GeV), and eA (HERA, 300A GeV) colliders.*

In Fig. 1 shown the dependence of TPL on the two-photon invariant mass for different colliding beams. The TPL function for e^+e^- (LEP2) was calculated with using Eq.(6) of ref. [7], as for the ep collision (HERA) the elastic part of the photon spectra from the proton was taken from [8]. Because of the used approximation the range of allowed W values in (3) is narrow (see Fig.1) as compared to (1) and defined by the condition $f(t^*) \geq 0$.
The advantage of eA collisions over e^+e^- and ep collisions lies in the Z^2 factor, which enchances the photon flux up to a factor 10^4. This allow, in the range of W below 40 GeV, the study of 'new phenomena' at HERA with large statistics.

3 Particle production processes

In this section we present a few examples of particle production in eA collisions through the two-photon mechanism. Processes with production of the 'old' particles (light hadrons and leptons) will create a background at search of 'new' particles (like Higgs bosons and sleptons). Cross sections presented here were calculated at $E_e = 27\,\text{GeV}$ and $E_A = E_p A$ with $E_p = 820\,\text{GeV}$.

[1] $L_{\gamma\gamma}$ is a dimensionless quantity. To get the production rate Eq. (2) have to be multiplied by the machine luminosity $\mathcal{L}_{eA}$ $[cm^{-2}sec^{-1}]$. For ion beams $\mathcal{L}_{eA} \sim A^{-1}\mathcal{L}_{ep}$.

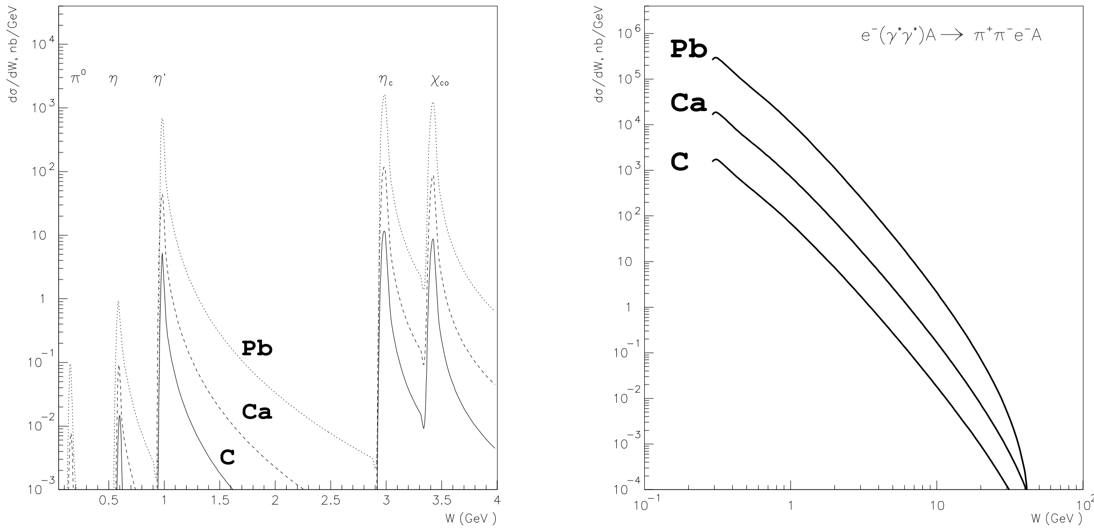

Figure 2: *Differential cross section for production of C-event pseudoscalar hadrons (a) and a* $\pi^+\pi^-$ *pair (b) as a function of* W *and a nucleus size.*

Resonances and pions

A region of the low mass in the two-photon system is the resonance region. C-even pseudoscalar hadrons - π^0, η, $\eta^{'}$, η_c, χ_{c0} - will be produced copiously at $W < 4$ GeV. Their production cross section $\sigma_{\gamma\gamma}$ is well known [1]. Therefore, Eqs. (2) and (3) allows easily to evaluate dependence of the production rate on W. Fig. 2a shows a resonance structure of the differential cross section (2) in that region. As another example the cross section (2) for pair production of charged pions is plotted in Fig. 2b. What can be measured in the above processes and how is discussed in details in [1]. We note here only, that the study of the angular and energy correlations between pions allows, in principle, to extract components of the amplitude $M_{ab}\,(a,\, b\, =\, +,\, -,\, 0)$ for the $\gamma\gamma \to f$ transition.

Lepton pairs

The Bethe-Heitler process is a source of lepton pairs with extremely high yield (Fig. 3). Copious production of τ-leptons provide an opportunity to study QCD in τ decay [9]. However it will also to complicate the Higgs boson search in lepton decay modes because the main background above the τ threshold is due to $\gamma^*\gamma^* \to \tau^+\tau^-$ (see below and Fig. 4c). How to suppress the Bethe-Heitler background is discussed in [10] (see also [14]).

SUSY particles

Non-strongly interacting sypersymmetric particles - sleptons and charginos- can be detected at the eA collider discussed here if their masses lies in the range $M_{sl} < 30$ GeV. Chargino couple to photons in the standard way of spin 1/2 fermions and sleptons are spin-zero particles. The two-photon cross section for production a pair of them can be found in [11], [1]. $\sigma(\gamma\gamma \to \tilde{l}^+\tilde{l}^-)$ is not logarithmically enhanced thus the production rate for sleptons is significantly lower than the chargino rate. As an example , the total cross section for slepton production versus the mass of the produced particle is shown Fig. 4a. At an integrated luminosity of $10^3/A\,\mathrm{pb}^{-1}$ only sleptons

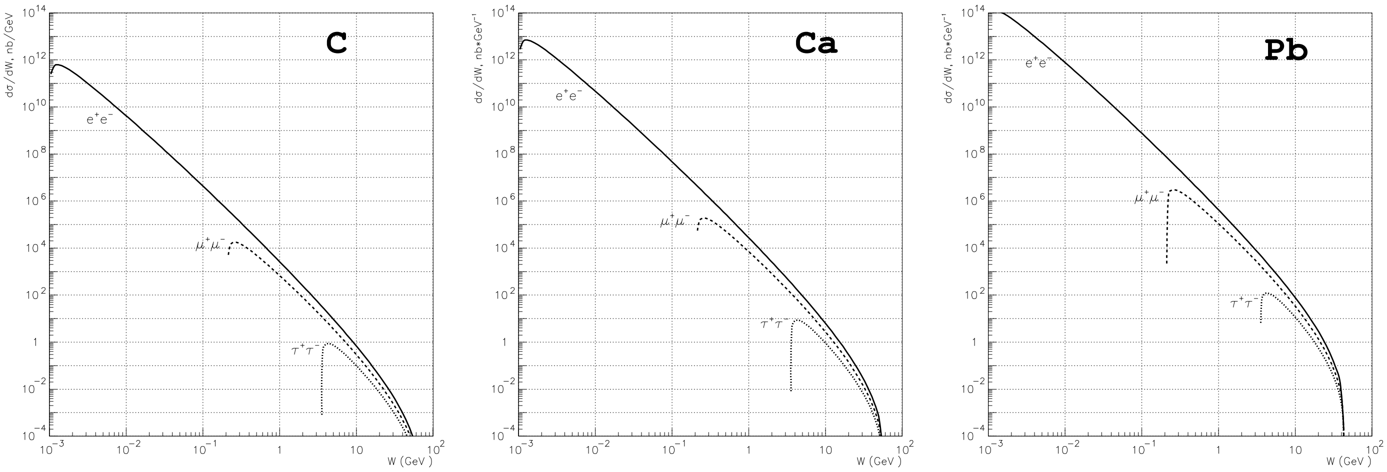

Figure 3: *Same as Fig. 2 for production of BH leptons in coherent eA collisions.*

with masses not heavier 29 GeV, 25 GeV and 20 GeV can be detected in eC, eCa, ePb collisions respectively.

Light neutral Higgs boson

The current mass limits on the Higgs particles from LEP data [12] restrict a class of models of spontaneous symmetry breaking available for analysis at HERA. The SM Higgs scalar and the MSSM scalar and pseudoscalar Higgs particles should be heavier than 66 GeV and 45 GeV, respectively. Minimal extension of the standard model like the general two doublet model (2HDM) [13] may yet have a very light ($\lesssim 40\,\mathrm{GeV}$) scalar h or pseudoscalar A[12, 14, 15]. The model parameters $tan\beta$ and α regulate coupling of Higgs particle to the "up" and "down" components of fermion doublets. We further restrict ourselves to the scenario with a large $tan\beta \sim \frac{m_t}{m_b} \gg 1$

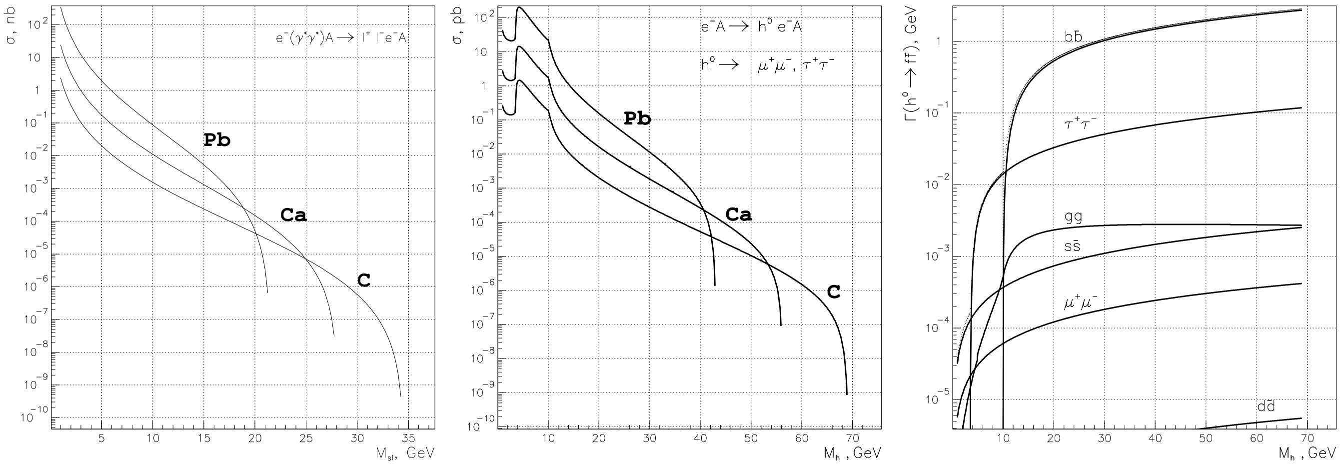

Figure 4: *Cross sections for slepton (a) and 2HDM light Higgs boson (b) production through two-photon fusion. The cross sections are plotted versus the mass of the produced particle. Also shown (c) the partial decay widths for h for $\tan\beta = 30\,(\alpha = \beta)$.*

and $\alpha = \beta$. This leads to the enhancement of the coupling to down-type fermions by factor $tan\beta^2$ for both h and A. We focus here on the resonant production of very light Higgs scalar h in the two-photon eA collisions[2].

The cross sections for the production of the h decaying into leptons versus the Higgs boson mass are presented in Fig. 4b. A specific structure of the curves is due to the variation of the h branchings (Fig.4c) with increasing the mass. Fig. 4b shows that at an integrated luminosity of $10/A\,\mathrm{pb}^{-1}$ there is a chance to observe the Higgs boson at HERA for $M_h \lesssim 5$ GeV, 8 GeV, 10 GeV in eC, eCa and ePb collisions respectively. However, at $\mathcal{L}_{eA} \sim 1/A$ pb^{-1} only ions with $A \sim 200$ produce sufficient photon flux for h production with mass $\sim 2M_\tau$.

4 Conclusion

Analysis of the last section shows that in the two-photon coherent eA collisions a number of the traditional processes (with hadron and lepton production) can be studied at HERA with high statistics. However, at $\mathcal{L}_{eA} \sim 1/A$ pb^{-1} only the restricted mass range $M_{\tilde{l}} < 13$ GeV can be explored in processes with SUSY particle production [6].

The general two Higgs doublet model provide a chance to study the Higgs production at HERA, since in framework of 2HDM light neutral Higgs particle is not rule out by present data. Therefore the search for the Higgs in the two-photon coherent eA interactions should be performed. Taking into account all results presented above it seems at an intergated luminosity $\sim 10/A$ pb^{-1} and higher beams of light-to-medium size ions ($A \sim 40$) will produce photon flux sufficient for study new phenomena in eA collisions at HERA .

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