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Nuclear γ-radiation as a Signature of Ultra Peripheral Ion Collisions at LHC energies

Preprint SINP MSU 2003-26/739

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Yu.V.Kharlov*, V.L.Korotkikh†

Аннотация

We study the peripheral ion collisions at LHC energies where a nucleus is excited a discrete state and then emits γ-rays. Large nuclear Lorenz factors allows the observation of high energy photons up to a few tens GeV and in the angular region of of a few hundred micro-radians from the beam direction. These photons can be used to tagg events with particle production in the central rapidity region in ultra-peripheral collisions. To detect these photons is necessary to have an electromagnetic detector in front of the zero degree calorimeter in the LHC experiments.

Introduction

There are several reviews devoted to coherent $\gamma\gamma$ and γg interactions in very peripheral collisions at relativistic ion colliders [1-3]. The advantage of relativistic heavy ion colliders is that the effective photon luminosity for two-photon physics is orders of magnitude higher than those available in e^+e^- machines. There have been many suggestions to use the electromagnetic interactions of nuclei to study production of meson resonances, Higgs bosons, Radions or exotic mesons. These interactions also probe fermion, vector meson or boson pair production, as well as investigate some new physics regions (see list in ref. [3]). The γg interactions will open a new area of nuclear physics such as the study of nuclear gluon distribution. It is also important for a knowledge of the details of medium effects in nuclear matter at the formation of quark-gluon plasma [4]. These effects may be studied by photo-production of heavy quarks in virtual photon-gluon interactions [4-6].

For these investigations it is necessary to select the processes with large impact parameters b of colliding nuclei, $b > (R_1 + R_2)$, to exclude background from strong interactions. Note, that some processes, like $\gamma\gamma$-fusion to Higgs bosons or Radions, are free from any problems caused by strong interactions of the initial state [7]. Therefore we need an efficient trigger to distinguish $\gamma\gamma$ and γg interactions from others. G.Baur et al., [8] suggested to detect intact nuclei after the interaction. Evidently this is impossible in the LHC experiments since the nuclei fly into the beam pipe.

It is interesting to consider γ rays emitted by the relativistic nuclei at LHC energies. This process was used for the possible explanation of the high energy ($E_\gamma \geq 10^{12}$ eV) cosmic photon spectrum [9].

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We had considered [10] the process $A + A \to A^* + A + e^+e^-, A^* \to A + \gamma'$, where a nucleus is excited by electron (positron) $e^\pm + A \to e^{\pm'} + A^*$, and suggested to detect a nuclear γ radiation after the excitation of discrete nuclear levels [10]. These secondary photons have the energy of a few GeV and a narrow angular distribution close the beam direction due to a large Lorentz boost. The angular width is large enough for them to be detected in the electromagnetic zero-degree calorimeters of the future LHC experiments CMS or ALICE.

Now we calculate the production process of some system X_f in $\gamma\gamma$ fusion with simultaneous excitation of discrete nuclear level. A nucleus retains its charge Z and mass A in this process. So we have a clear electromagnetic interaction of nuclei at any impact parameter. The nuclear γ radiation may be used as "event-by-event" criteria in these collisions.

In this work we consider the processes

$$^{16}\mathrm{O} +^{16}\mathrm{O} \to^{16}\mathrm{O} +^{16}\mathrm{O}^*(2^+, 6.92\ \mathrm{MeV}) + X_f, ^{16}\mathrm{O}^* \to^{16}\mathrm{O} + \gamma,$$

$$^{208}\mathrm{Pb} +^{208}\mathrm{Pb} \to^{208}\mathrm{Pb} +^{208}\mathrm{Pb}^*(3^-, 2.62\ \mathrm{MeV}) + X_f, ^{208}\mathrm{Pb}^* \to^{208}\mathrm{Pb} + \gamma,$$

where the ^{16}O and ^{208}Pb were taken since they are the lightest and heaviest ions in the LHC program. The trigger requirements will include a signal in the central rapidity region of particles from X_f decay, a signal of photons in the electromagnetic detector in front of the zero degree calorimeter and a veto signal of neutrons in ZDC. We suggest to use the veto signal of neutrons in order to avoid the processes with nuclear decay into nucleon fragments.

The formalism of the considered process is presented in section 1. The nuclear form factors are calculated in section 2. The angular and energy distributions of secondary photons are in section 3. The cross sections of $\eta_c(2.979\ \mathrm{GeV})$ production are presented in the part 4 with and without nuclear excitation. The section 5 is our conclusion.

1 Formulae of nuclear excitation cross-section and photon luminosity in peripheral interactions

Let us consider the peripheral ion collision

$$A_1 + A_2 \to A_1^*(\lambda^P, E_0) + A_2 + X_f, \tag{1}$$

where X_f is the produced system in $\gamma^*\gamma^*$ fusion and A_1^* is an excited nucleus in a discrete nuclear state with spin-parity λ^P and energy E_0 (see Fig.1). Here the nucleus A_1 and A_2 have equal mass A and charge Z, the only nucleus A_1 is excited. We suppose that the reaction product X_f decay can be detected in the central rapidity region. The nuclear γ radiation $A_1^* \to A_1 + \gamma$ will be measured in the forward detectors such as ZDC.

We use the quantum mechanical plane wave formalism [3],[11] and the derivation of the equivalent photon approximation. It allows us to introduce the elastic and inelastic nuclear form factors for the process (1). We take the formulae (19) and (21) in [3] :

$$d\sigma_{A_1A_2 \to A_1^*A_2X_f} = \int \frac{dw_1}{w_1} \int \frac{dw_2}{w_2} n_1(w_1) n_2(w_2) d\sigma_{\gamma\gamma \to X_f}(w_1, w_2), \tag{2}$$

$$n_i(w_i) = \frac{\alpha}{\pi^2} \int d^2q_{i\perp} \int d\nu_i \frac{1}{(q_i^2)^2} \left[2\frac{w_i^2 m_i^2}{P_i^2} W_{i,1}(\nu_i, q_i^2) + q_{i\perp}^2 W_{i,2}(\nu_i, q_i^2) \right], \tag{3}$$

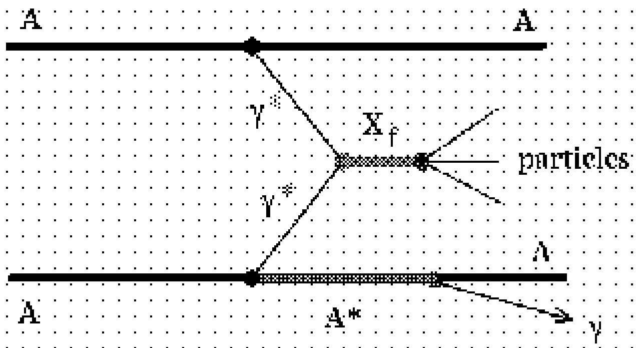

Рис. 1: Diagram of the process $A_1 + A_2 \to A_1^*(\lambda^P, E_0) + A_2 + X_f$, $A_1^* \to A_1 + \gamma$.

where $W_{i,1}$ and $W_{i,2}$ are the Lorentz scalar functions. All kinematic variables are the same definitionsas in [3].

For "elastic" photon process $A_1A_2 \to A_1A_2X_f$ we have

$$W_1 = 0, \;\; W_2(\nu, q^2) = Z^2F_{el}^2(-q^2)\delta(\nu + q^2/2m) \tag{4}$$

So that [3]:

$$n(w) = \frac{Z^2\alpha}{\pi^2}\int d^2q_\perp \frac{q_\perp^2}{(q^2)^2}F_{el}^2(-q^2), \tag{5}$$

where $F_{el}(q)$ is the nuclear form-factor with $F_{el}(0) = 1$.

For the excitation of nucleus to a discrete state with a spin λ and an energy E_0 ("inelastic" photon process $A_1A_2 \to A_1^*(\lambda^P, E_0)A_2X_f$)

$$\begin{aligned} W_{1,2}(\nu, q^2) &= \hat{W}_{1,2}(q^2)\delta(\nu - E_0), \\ -q^2 &= \frac{w^2}{\gamma^2} + 2\frac{wE_0}{\gamma} + \frac{E_0^2}{\gamma^2} + q_\perp^2, \\ \hat{W}_1 &= 2\pi[|T^e|^2 + |T^m|^2], \\ \hat{W}_2 &= 2\pi\frac{q^4}{(E_0^2 - q^2)^2}\left[2|M^c|^2 - \frac{E_0^2 - q^2}{q^2}(|T^e|^2 + |T^m|^2)\right]. \end{aligned} \tag{6}$$

See notations again in [3].

We neglect the transverse electric T^e and transverse magnetic T^m matrix elements compared to the Coulomb one $M^c \equiv M_\lambda$ for $0^+ \to \lambda^P$ nuclear transitions. Then for the "inelastic" photon process with a nuclear discrete state excitation we get

$$n_1^{(\lambda)}(w) = \frac{4\alpha}{\pi}\int d^2q_\perp \frac{q_\perp^2}{(E_0^2 - q^2)^2}|M_\lambda(-q^2)|^2, \tag{7}$$

where $M_\lambda(q)$ is the inelastic nuclear form-factor and $-q^2 = q_L^2(w) + q_\perp^2$.

The equivalent photon number (7) can be represented as function of $q_\perp$ for inelastic photon emission:

$$\begin{aligned} \frac{dn_1^{(\lambda)}}{dq_\perp^2}(w_1, q_\perp) &= \frac{4\alpha}{\pi}\frac{q_\perp^2}{(E_0^2 - q^2)^2}|M_\lambda(-q^2)|^2 = \\ &= \frac{4\alpha}{\pi}\left|\frac{q_\perp}{(E_0^2 - q^2)}M_\lambda(-q^2)e^{i\varphi_\perp}\right|^2, \end{aligned} \tag{8}$$

where $q_\perp e^{i\varphi_\perp} = \vec{q}_\perp$ (see [12]).

Let us do the inverse transformation to the impact parameter b presentation

$$f(\vec{b}) = \frac{1}{2\pi}\int d^2 q_\perp e^{-i\vec{q}_\perp\vec{b}} f(\vec{q}_\perp). \tag{9}$$

For the function under the module in equation (8) we get

$$\begin{aligned} f(\vec{b}) &= \frac{1}{2\pi}\int d^2 q_\perp \frac{q_\perp}{(E_0^2 - q^2)} M_\lambda(-q^2) e^{i\varphi_\perp} \cdot e^{-i\vec{q}_\perp\vec{b}} = \\ &= i\int dq_\perp \frac{q_\perp^2}{(E_0^2 - q^2)} M_\lambda(-q^2)\cdot J_1(q_\perp b) = \\ &= \frac{i}{b}\int du \frac{u^2}{u^2 + (E_0^2 + q_L^2)\, b^2} M_\lambda\left(-\frac{x^2+u^2}{b^2}\right) J_1(u). \end{aligned} \tag{10}$$

Here $x = q_L b = wb/\gamma_A$ and $u = q_\perp b$.

If we take M_{el} instead of the inelastic M_λ as

$$|M_{el}(-q^2)|^2 = \frac{Z^2}{4\pi} F_{el}^2(-q^2) \tag{11}$$

and put $E_0 = 0.$, then we get a well-known formula of impact parameter-dependent equivalent photon number of A_2 nucleus (see (4) in [12]):

$$N_2^{(el)}(w,b) = \frac{Z^2\alpha}{\pi^2}\frac{1}{b^2}\left|\int du \frac{u^2}{x^2+u^2} J_1(u) F_{el}[-(x^2+u^2)/b^2]\right|^2, \tag{12}$$

For a point charge, $F_{el}(q) \equiv 1$, we readily obtain

$$N_2^{(el)}(w,b) = \frac{Z^2\alpha}{\pi^2}\frac{1}{b^2}\; x^2\; K_1^2(x), \tag{13}$$

in agreement with [3] at very large γ_A.

We write the form factors of the elastic and inelastic nuclear process in the same forms:

$$\mathcal{F}_\lambda^2(q) = \frac{1}{4\pi e^2 Z^2} F_\lambda^2(q) \tag{14}$$

$$F_0^2(q) = \left|4\pi\frac{1}{q}\int \sin(qr)\rho_0(r) r\, dr\right|^2_{q\to 0} \to 1, \tag{15}$$

$$F_\lambda^2(q) = (2\lambda+1)\left|4\pi\int j_\lambda(qr)\rho_\lambda(r,Z) r^2 dr\right|^2_{q\to 0} \to \tag{16}$$

$$\to \frac{(4\pi)^2 B(E\lambda)}{e^2 Z^2[(2\lambda+1)!!]^2}\; q^{2\lambda}, \tag{17}$$

where $\rho_\lambda(r,Z)$ is an nuclear transition density and $B(E_0\lambda)$ is the reduced transition probability .

Then for the matrix elements M_λ we get in the limit $q \to 0$

$$|M_{el}(-q^2)|^2 = \left(\frac{Z^2}{4\pi}\right) F_{el}^2(q)\,\Big|_{q\to 0} \to \frac{Z^2}{4\pi} \tag{18}$$

$$|M_\lambda(-q^2)|^2 = \left(\frac{Z^2}{4\pi}\right) F_\lambda^2(q) \Big|_{q\to 0} \to \left(\frac{Z^2}{4\pi}\right) \frac{(4\pi)^2 B(E_0\lambda)}{e^2 Z^2[(2\lambda+1)!!]^2} q^{2\lambda}. \tag{19}$$

The equivalent photon number for inelastic process with A_1 nuclear transition $0 \to \lambda$ will be

$$N_1^{(\lambda)}(w,b) = \frac{Z^2\alpha}{\pi^2}\frac{1}{b^2}\left|\int_0^\infty du \frac{u^2}{x_{in}^2+u^2} J_1(u) F_\lambda[-(x_{in}^2+u^2)/b^2]\right|^2, \tag{20}$$

as the generalization of (12). Here $x_{in}^2 = (E_0^2 + \frac{w^2}{\gamma^2} + 2\frac{wE_0}{\gamma} + \frac{E_0^2}{\gamma^2})\, b^2$.

We take the inelastic form-factor from inelastic electron scattering off nuclei. A good parameterization of inelastic form-factor is

$$F_\lambda^2(q) = 4\pi\beta_\lambda^2 j_\lambda^2(qR) e^{-q^2 g^2} \tag{21}$$

in the Helm's model [13]. The squared transition radius is equal to $R_\lambda^2 = R^2 + (2\lambda+3)g^2$, where R and g are the model parameters.

According to (19) the reduced transition probability in this case is equal to

$$B(E_0\lambda) = \frac{\beta_\lambda^2}{4\pi} Z^2 e^2 R^{2\lambda}. \tag{22}$$

So, the formulae for the process (1) are

$$d\sigma_{A_1A_2\to A_1^*A_2X_f} = \int \frac{dw_1}{w_1}\int\frac{dw_2}{w_2} n_1^{(\lambda)}(w_1) n_2(w_2) d\sigma_{\gamma\gamma\to X_f}(w_1,w_2); \tag{23}$$

$$n_1^{(\lambda)}(w_1) = \frac{Z^2\alpha}{\pi^2}\int d^2q_\perp \frac{q_\perp^2}{(E_0^2 - q_{in}^2)^2} |F_\lambda(-q_{in}^2)|^2; \tag{24}$$

$$-q_{in}^2 = \frac{w^2}{\gamma_A^2} + 2\frac{wE_0}{\gamma_A} + \frac{E_0^2}{\gamma_A^2} + q_\perp^2; \tag{25}$$

$$n_2(w_2) = \frac{Z^2\alpha}{\pi^2}\int d^2q_\perp \frac{q_\perp^2}{q_{el}^4} F_{el}^2(-q_{el}^2); \tag{26}$$

$$-q_{el}^2 = \left(\frac{w}{\gamma_A}\right)^2 + q_\perp^2. \tag{27}$$

The value q_{in}^2 is close to q_{el}^2 at a large γ_A factor at LHC energies.

The effective two photon luminosity can be expressed as

$$L(\omega_1,\omega_2) = 2\pi \int_{R_1}^\infty b_1 db_1 \int_{R_2}^\infty b_2 db_2 \int_0^{2\pi} d\phi N_1^{(\lambda)}(\omega_1,b_1) N_2^{(el)}(\omega_2,b_2)\Theta(B^2), \tag{28}$$

where R_1 and R_2 are the nuclear radii, $\Theta(B^2)$ is the step function and $B^2 = b_1^2 + b_2^2 - 2b_1b_2\cos\phi - (R_1+R_2)^2$ [3]. Then the final cross-section is

$$\sigma_{A_1A_2\to A_1^*A_2X_f} = \int\frac{d\omega_1}{\omega_1}\int\frac{d\omega_2}{\omega_2} L(\omega_1,\omega_2)\ \sigma_{\gamma\gamma\to X_f}(w_1,w_2) \tag{29}$$

2 Nuclear levels and form-factors

The elastic form factor of a light nucleus is

$$F_{el}(q^2) = \exp\left(-\frac{\langle r^2 \rangle}{6}\, q^2\right) \tag{30}$$

with $\sqrt{\langle r^2 \rangle} = 2.73$ fm for the nucleus ^{16}O. For a heavy nucleus we take a modified Fermi nuclear density [14]

$$\rho(r) = \rho_0 \left\{ \frac{1}{1 + exp\frac{-r-R}{g}} + \frac{1}{1 + exp\frac{r-R}{g}} - 1 \right\} \tag{31}$$

$$= \rho_0 \frac{sh(R/g)}{ch(R/g) + ch(r/g)}, \tag{32}$$

$$\rho_0 = \frac{3}{4\pi R^3} \left\{ 1 + \left(\frac{\pi g}{R}\right)^2 \right\}^{-1} \tag{33}$$

with the parameters for ^{208}Pb are equal to $R = 6.69$ fm, $g = 0.545$ fm. Such form of density is close to the usual Fermi density at $g \ll R$

$$\rho_F(r) = \rho_0 \frac{1}{1 + \exp\frac{r-R}{g}} \tag{34}$$

and allows us to calculate the elastic form factor analytically

$$F_{el}(q) = \frac{4\pi^2 R g \rho_0}{q\, \mathrm{sh}(\pi g q)} \left\{ \frac{\pi g}{R}\, \sin(qR)\, \mathrm{cth}(\pi g q) - \cos(qR) \right\}. \tag{35}$$

There are a few discrete levels of ^{16}O below α, p and n thresholds $E_{th}(\alpha) = 7.16$ MeV, $E_{th}(p) = 12.1$ MeV, $E_{th}(n) = 15.7$ MeV [15]. The level 2^+ at $E_0 = 6.92$ MeV is the strongest excited one in the electron scattering.

The parameters from the inelastic electron scattering fit on ^{16}O with excitation of 2^+ level ($E_0 = 6.92$ MeV) of are [16]:

$$\beta_2 = 0.30, \quad R = 2.98 \text{ fm}, \quad g = 0.93 \text{ fm}.$$

They correspond to

$$B(E_0 2) = (36.1 \pm 3.4) e^2 \text{ fm}^4. \tag{36}$$

There are more than 70 discrete levels of ^{208}Pb [17] below the neutron threshold $E_{th}(n) = 7.367$ MeV. About 30% of the levels decay to the first 3^- level of ^{208}Pb at $E_0 = 2.615$ MeV. This level is well studied experimentally [18] and has a large cross-section of excitation.

The reduced transition probability from the fit of inelastic electron scattering on ^{208}Pb with excitation of the 3^- level is [18]:

$$B(E_0 3) = (6.12\ 10^5 \pm\ 2.2\%) e^2 \text{ fm}^6. \tag{37}$$

We calculate the parameter β_3, using this $B(E_0 3)$, and take R and g from the density of the ^{208}Pb ground state:

$$\beta_3 = 0.113, \quad R = 6.69 \text{ fm}, \quad g = 0.545 \text{ fm}.$$

Note that there are many levels higher than $E_0 = 2.615$ MeV which decay to the first level of ^{208}Pb. This fact increases the event rate of the process (1), but we do not know the excitation cross-section of these levels.

The elastic form factor (30) of ^{16}O and inelastic form-factor ^{16}O $(2^+, 6.92$ MeV) (21), corresponding to the electron scattering data, are shown in Fig. 2. The same for a nucleus ^{208}Pb and the exited state ^{208}Pb $(3^-, 2.64$ MeV) are shown in Fig. 3.

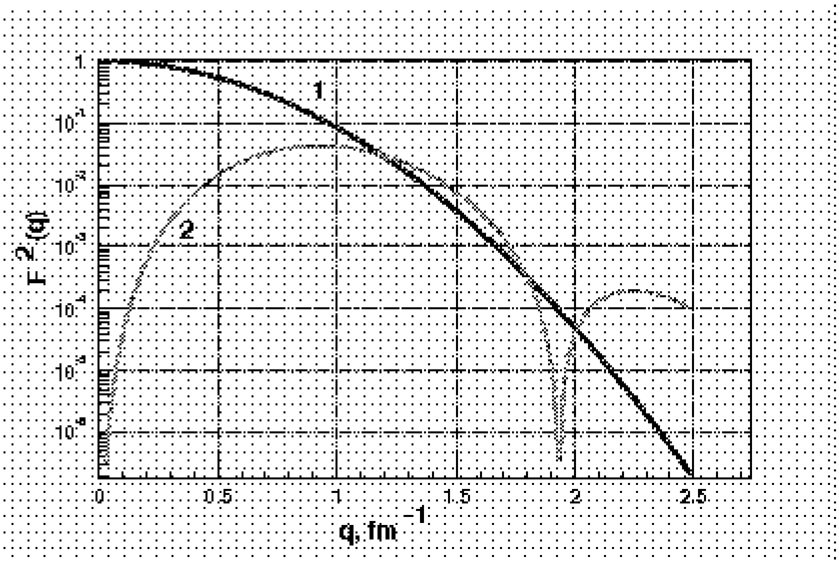

Рис. 2: The elastic form-factor (1) of ^{16}O and the inelastic form-factor (2) of ^{16}O $(2^+, 6.92$ MeV) from the electron scattering.

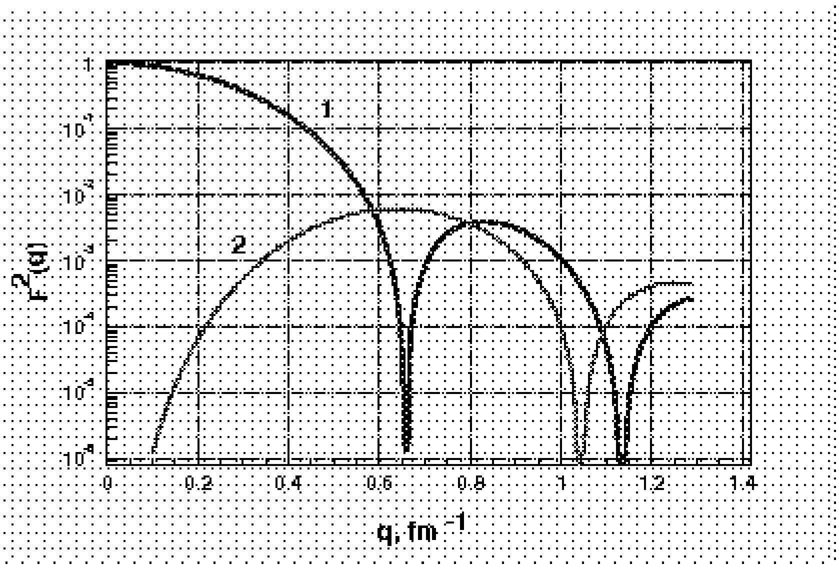

Рис. 3: The elastic form-factor (1) of ^{208}Pb and the inelastic form-factor (2) of ^{208}Pb $(3^-, 2.615$ MeV) .

The squared inelastic form-factor is less than the elastic form-factor by more then two orders at small $q < q_0$ ($q_0 = 0.5$ fm^{-1} for ^{16}O and $q_0 = 0.4$ fm^{-1} for ^{208}Pb). In the region of $q > q_0$ they are comparable. The region of large $q > q_0$ will give contribution for the small impact parameter b. We are able to calculate the photon luminosity (28) for all regions of

b to get the maximum electromagnetic cross-section of process we are interested in. Then it should be possible to compare with experimental data in the condition of clear selection of such process by the photon signal and the veto neutron or proton signal in ZDC.

3 Angular and energy distributions of secondary nuclear photons

We suppose that the nucleus $A_1^*(\lambda\mu)$ in the process (1) is unpolarized. Just now we don't know the relative excitation probability of $|\lambda\mu>$ states, where μ is a projection of spin λ. This assumption needs the study in future. So we use a formula (27) in our work [10] for the angular distribution of secondary photons, which is valid for isotropic photon distribution in the rest system of A_1^* according to equal probabilities of excitation.

If we calculate the integral cross-section of reaction (1) using Eq. (29) then the angular and energy distribution of photons are equal to [10]:

$$\frac{d\sigma_{A^*}}{d\theta_\gamma} = \sigma_{A_1 A_2 \to A_1^* A_2 X} \cdot \frac{2\gamma_{A_1^*}^2 \sin\theta_\gamma}{(1+\gamma_{A_1^*}^2 \tan^2\theta_\gamma)^2 \cdot \cos^3\theta_\gamma}, \tag{38}$$

$$\frac{d\sigma_{A^*}}{dE_\gamma} = \sigma_{A_1 A_2 \to A_1^* A_2 X} \cdot \frac{\Theta(2\gamma_{A_1^*}E_0 - E_\gamma)}{2\gamma_{A_1^*}E_0}, \tag{39}$$

where $\Theta(x)$ is a step function.

The angular distribution does not depend on photon energy and the energy distribution is uniform.

The photon energy E_γ and the polar angle θ_γ in laboratory system are defined as:

$$E_\gamma = \gamma_{A_1^*}E_0(1+\cos\theta'_\gamma) = 2\gamma_{A_1^*}E_0/(1+\gamma_{A_1^*}^2\tan^2\theta_\gamma), \tag{40}$$

$$\tan\theta_\gamma = \frac{1}{\gamma_{A_1^*}} \frac{\sin\theta'_\gamma}{1+\cos\theta'_\gamma}, \tag{41}$$

where θ'_γ and θ_γ are the polar angles of nuclear photon in the rest nuclear system and in the laboratory system with an axis $\vec{z}||\vec{p}_{A^*}$. The photon energy E_γ dependence on θ_γ is shown in Fig. 4. Thus the energy E_γ will depend on the position of photon hit.

Our calculations with the TPHIC event generator [19] show that a deflection of the direction $\vec{p}_{A^*}$ from $\vec{p}_{beam}$ at LHC energies in the reaction (1) is very small at large γ_A, $\langle\Delta\theta\rangle \simeq 0.5$ μrad.

In the experiments CMS and ALICE, which are planned at LHC (CERN), the Zero Degree Calorimeter ([20], [21]) was suggested for the registration of nuclear neutrons after ion interaction. We demonstrate a schematic figure of the ZDC CMS at a distance $L = 140$ m in the plane transverse to the beam direction in Fig. 5. The CMS group also plans to include the electromagnetic calorimeter in front of the ZDC.

As an example we demonstrate the angular distributions (38) in arbitrary units and energy dependence (40) on the (x, y) coordinates of the ZDC CMS for two nuclei ^{16}O and ^{208}Pb in Fig. 6. The direction of the nucleus A_1^* coincides here the beam direction. The point $(x, y) = (0, 0)$ is the center of the ZDC plane.

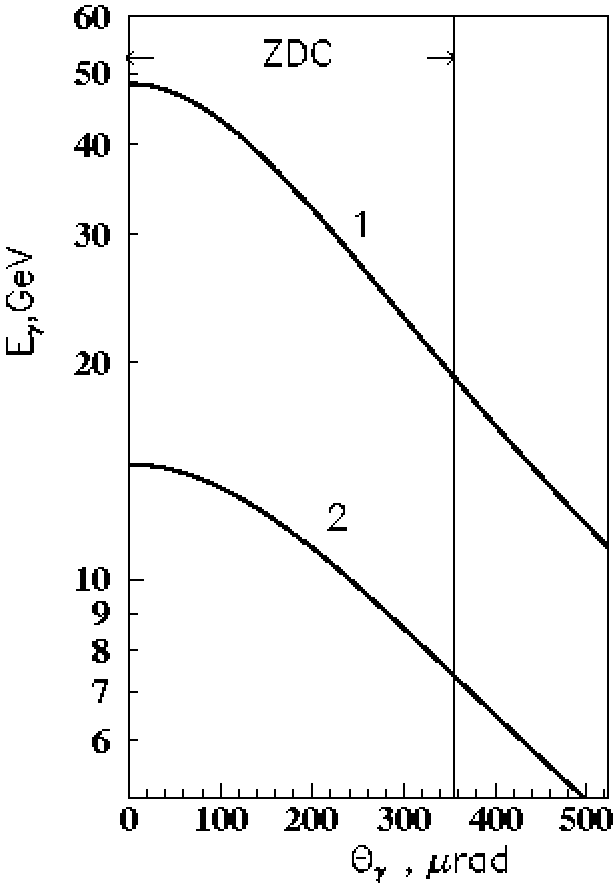

Рис. 4: Nuclear photon energy as function of its polar angle in the laboratory system at LHC energies for two nuclei: ^{16}O ($2^+ \to 0^+, 6.92$ MeV) (1) and ^{208}Pb ($3^- \to 0^+, 2.615$ MeV) (2). ZDC marks a region of Zero Degree Calorimeter in CMS.

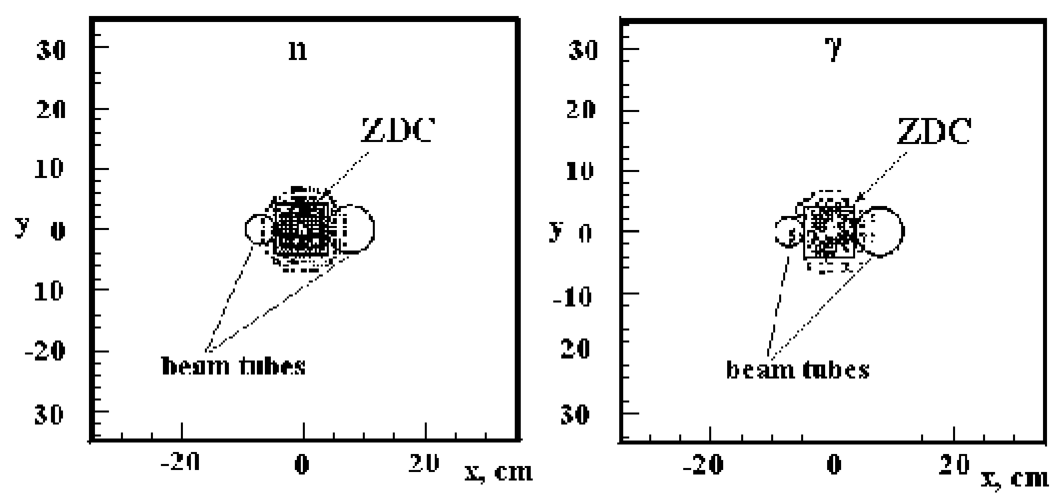

Рис. 5: Transverse ZDC plane. The points are the simulated hits of neutrons (left) and photons (right) from a work ([21]).

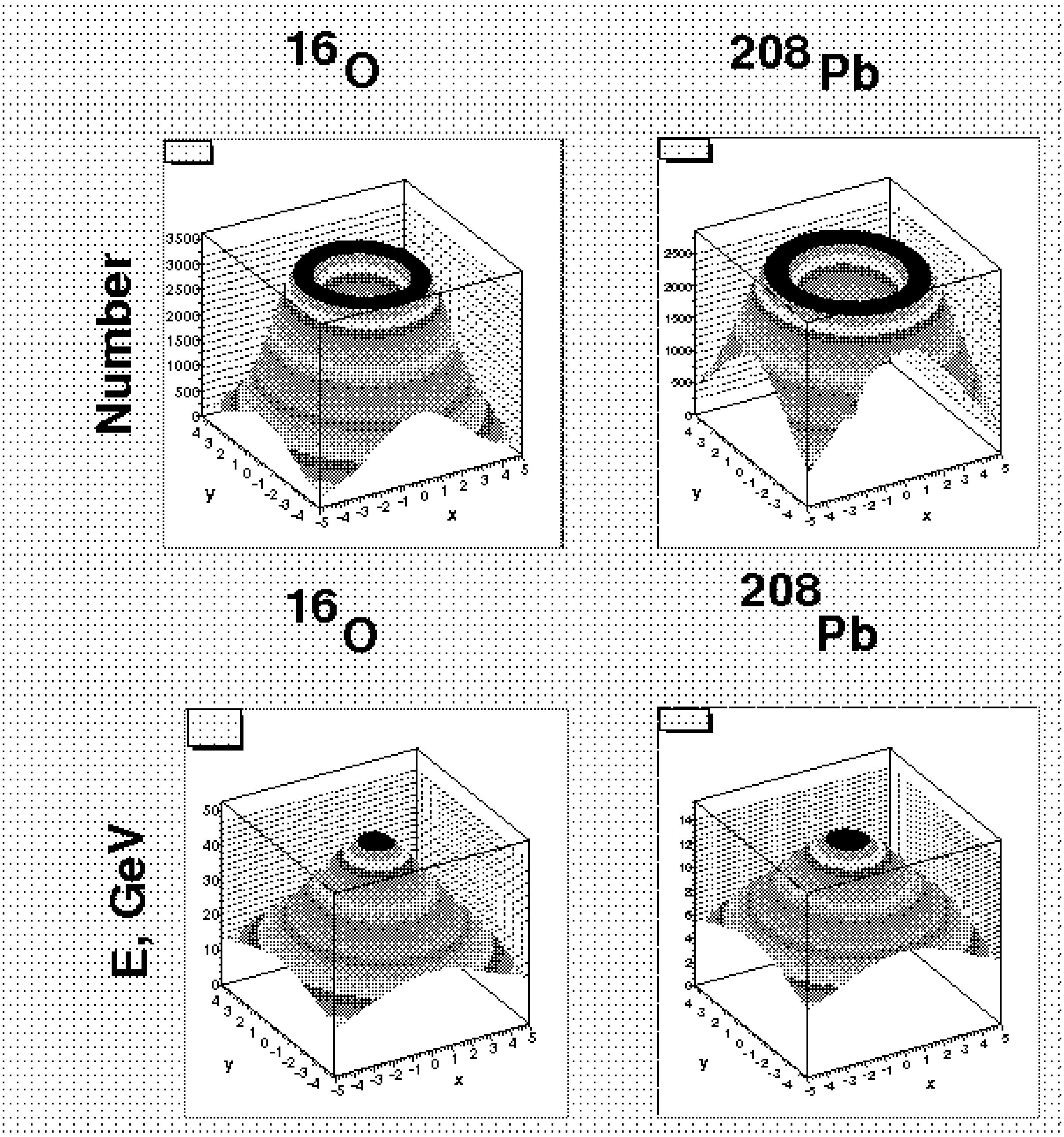

Рис. 6: The photon angular distributions (upper row) and the energy dependence (lower row) for $^{16}O^*(2^+, 6.92$ MeV) (left colomn) and $^{208}Pb^*(3^-, 2.62$ MeV) (right colomn) radiation decay in the laboratory system on the ZDC plane (x, y) at the distance 140 m from point interaction. x, cm is a horizontal and y, cm is a vertical axis. Photon energy interval in ZDC region is $19 \div 48$ GeV for $^{16}O^*(2^+)$ and $7 \div 14$ GeV for $^{208}Pb^*(3^-)$.

4 Cross-section of the process with the nuclear γ radiation

We demonstrate our results for $\eta_c(2.979)$ production. The previous results [3] used old values of the widths and a point nuclear charge. Now we take resonance parameters from the review of particle physics ([22]), $\Gamma_{\eta_c \to \gamma\gamma} = 4.8$ keV, and a realistic charge distribution. The calculations was made with the help of TPHIC event generator [19]. We use a well known formula [2] of a narrow resonance cross-section

$$\sigma_{\gamma\gamma \to X}(w_1, w_2) = 8\pi^2(2\lambda_X + 1)\Gamma_{X\to\gamma\gamma}\delta(W^2 - M_X^2)/M_X \tag{42}$$

where $W^2 = 4w_1w_2$, λ_X and M_X is the spin and mass of the resonance. The LHC luminosity and our results according to (29) and (28) are in Table 1 for the process (1) with $A_{final} = A_1$ or A_1^*.

Таблица 1: Cross-section of η_c production by $\gamma\gamma$ fusion

A_{final}	L (cm^{-2} s^{-1})	L (pb^{-1})	σ	event/10^6 s
η_c (2.979 GeV)				
A point charge of the nuclei				
$^{208}Pb_{82}$	$4.2 \cdot 10^{26}$	0.00042	356 μb	147000
$^{16}O_8$	$1.4 \cdot 10^{31}$	14.0	73 nb	1020000
With form-factors of nucleus and in the region $R < b < \infty$				
$^{208}Pb_{82}$	$4.2 \cdot 10^{26}$	0.00042	296 μb	122000
$^{208}Pb^*_{82}$ (3^-)	$4.2 \cdot 10^{26}$	0.00042	129 nb	53
$^{16}O_8$	$1.4 \cdot 10^{31}$	14.0	66 nb	926000
$^{16}O^*_8$ (2^+)	$1.4 \cdot 10^{31}$	14.0	0.201 nb	2810

Our results in a Table 1 shows that though the cross-section of the process (1) for the nucleus ^{208}Pb is larger than that for ^{16}O, the event rate is smaller because of the lower LHC luminosity for ^{208}Pb. The cross section with a nuclear excitation is smaller by three orders of magnitude than that without the excitation since the intensity of excitation is not large and a inelastic form factor is smaller than the elastic form factor (see Fig. 2 and 3). Therefore for the accepted LHC luminosities it is possible to use secondary photons as a signature of clear electromagnetic nuclear processes only for the production X_f with rather large cross-section $\sigma_{\gamma\gamma\to X}$. The light ions are more preferable than the heavy ions to detect the nuclear γ radiation.

5 Conclusion

In this work we suggest a new signature of the peripheral ion collisions.

The formalism of the process (1) is developed in the frame of the equivalent photon approximation. New point is an introduction of the inelastic nuclear form factor. It allows to consider the excitation of discrete nuclear levels and their following γ radiation decay. It is shown that the energy of this secondary photons are in GeV region due to a large Lorentz boost at LHC energies. The angular distribution of the photons has a peculiar form as a function of polar angle in the beam direction. The most photons fly in the region of angles of a few hundred micro-radians, which are those detactable in the ZDC CMS and ALICE experiments.

Thus the nuclear γ radiation is a good signature of the clear peripheral ion collisions at LHC energies when A and Z of beam ion are conserved. The trigger requirements will include a signal in the central rapidity region of particles from X_f decay, a signal of photons in the electromagnetic detector in front of the zero degree calorimeter and a veto signal of neutrons in ZDC. We suggest to use the veto signal of neutron in order to avoid the processes with nuclear decay into nucleon fragments. The nuclear γ radiation can be used for tagging the events with particle production in the central rapidity region in the ultra-peripheral collisions.

The light nuclei are more preferable comparing with heavy ions since they have higher beam luminosity at LHC. The cross-sections of the process with the nuclear excitation is three orders of magnitude smaller than one without excitation. The accepted nuclear luminosities enable to use this signature for the large cross section of X_f system production.

Authors are very grateful to L.I.Sarycheva and S.A.Sadovsky for the useful discussions and K. Hencken and R. Vogt for helpful comments.

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Препринт НИИЯФ МГУ 2003-26/739

Работа поступила в ОНТИ 11.12.2003 г.

ИД №00545 от 06.12.1999 г.

Издательство УНЦ ДО

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Гигиенический сертификат №77.99.2.923.Д.001743.03.03 от 11.03.2003
Налоговые льготы — Общероссийский классификатор продукции
ОК–005–93, том 1 — 953000

Заказное. Подписано в печать 16.12.2003 2003 г. Формат $60 \times 90/16$
Бумага офсетная №2. Усл. печ. л. 1
Тираж 50 экз. Заказ №529

Отпечатано в Мини-типографии УНЦ ДО
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представленного оригинал-макета