THE LINEARLY POLARIZED PHOTON BEAM FOR PHOTONUCLEAR INVESTIGATIONS AT NEW NSC KIPT FACILITY

V.B. Ganenko*, G.A. Vashchenko, D.D. Burdeynyi

National Science Center "Kharkov Institute of Physics and Technology", 61108, Kharkov , Ukraine

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Intensity and polarization spectrums of coherent bremsstrahlung for the designed facility NSC KIPT (project SALO) for two possible channels of output of electron beam from accelerator with the maximal energies of beam 490 and 730 MeV are calculated. It is shown, that at the definite conditions of forming the beam it is possible to obtain the CB beams with intensity and polarization, sufficient for conducting of experimental researches in the interval of energies of photons about 400 MeV on the beam line with the maximal electron energy about 730 MeV, and in interval about 250 MeV on the beam line with the maximal electron energy about 490 MeV.

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1. INTRODUCTION

At present and in foreseeable future fundamental nuclear physic investigations will be of great importance both in low (from tens MeV) and high (up to TeV) energy range from point of view of searching answers on substantial questions of natural science, such as the elementary particles structure, matter evolution, on one hand, and the possibility of practical application of the fundamental investigation results, on other hand [1]. To provide these investigations new accelerator facilities are created, e.g. LHC and FIAR, and operative facilities are constantly upgraded, e.g. electron accelerators at intermediate energies MAMI and Jlab.

The project of new accelerator facility (project SALO) aimed on fundamental photonuclear investigations in intermediate energy range is discussed in NSC KIPT [2, 3]. The supposed accelerator parameters: maximal electron energy up to 730 MeV, current up to 100 mkA, duty cycle $\sim 100\%$, will provide possibilities for production both polarized and unpolarized continues electron and photon beams that will allow to perform high level experiments with electromagnetic probes in intermediate energy range. These experiments could be aimed on studying fundamental problems, such as precision test and development QCD approach in intermediate and low energy range, e.g. ChPT, study hadron structure and it changes in the nuclear matter, baryon mass spectrum, fundamental symmetries violation etc. These problems decision require performing a wide experimental program on studying single and pair pion photoproduction on nucleon and nuclei near threshold, Compton scattering on nucleon and nuclei, η-nuclei photoproduction, electron scattering on nucleon and nuclei [4, 5]. The experiments with polarized photon beam will play very important part in such investigations and one of the main requirements for them will be high accuracy of the measurements.

Under SALO accelerator conditions the linearly polarized photon beam could be produced on the base of coherent bremsstrahlung radiation (CB) generated by relativistic electrons in diamond crystal. The diamond crystal due to high Debye temperature, perfect crystal lattice and small atomic number provides most high operating parameters (intensity and polarization) of the beam. As is known, in consequence of periodicity of the atom location in the crystal lattice, when relativistic electrons fall onto the crystal at a small angle ψ relative to the crystal axes (but exceeding substantially a critical angle of axial channeling, $\psi >> \psi_c$) interference maxima appear in the radiation spectra. The radiation intensity in these maxima substantially exceeds the radiation intensity in an amorphous material and in addition the radiation in it has a significant linear polarization.

The spectrum and polarization of the CB are well described by theory based on Born approximation. According to [6, 7, 8] the CB cross section can be represented as:

$$d\sigma_{CB} = d\sigma_{in} + d\sigma_{coh},$$

where $d\sigma_{coh}$ is the interference part of the CB cross section depending on the crystal orientation relatively to the electron beam; $d\sigma_{in}$ is the non-coherent part of the cross section, which does not depend on the crystal orientation and represents itself a cross section of usual bremsstrahlung in the amorphous substance. Thus, CB beam spectrum consists of two parts: coherent part with interference maximum and usual bremsstrahlung. The interference peak has a

*Corresponding author. E-mail address: ganenko@kipt.kharkov.ua

sharp upper border and is reduced slowly in the low-energy area. With increasing angle ψ the radiation intensity in the peak falls, the peak itself is displaced to higher energy range and at large ψ it is not observed.

The CB beams were created practically at every electron accelerators with beam energy of $E_0 \sim 1\,GeV$ [9]. At present the CB beams are successfully being used in Mainz [10] and at the Jefferson Laboratory in USA [11]. As the polarized photon beam is necessary for providing experimental photonuclear program at NSC KIPT on the SALO facility [5], we have studied a possibility of the linear polarized photon beam creation on the base of CB electrons in the diamond crystal and estimated expected parameters of such beam.

2. RESULTS AND DISCUSSION

The SALO project facility lay out [2, 3] is shown in Fig.1. The electron accelerator (superconducting recirculator) is placed in the existing room of the $LU-2\,GeV$ facility. The proposed accelerating structure will give growth energy rate $20\,MeV/m$ and provide increasing of the electron beam energy on $240\,MeV$ after each passing through it. The magnetic system will allow make only three passing the beam through the accelerating structure so maximal energy of the electron beam will reach $730\,MeV$, if one will take into account exit energy from injector ($\sim 10\,MeV$), along the lines to the experimental Hall $SP-103$ of the old linac $LU-2\,GeV$. There is an intention to construct two beam lines in $SP-103$ Hall, Fig 1: the first beam line for experiments with real tagged photons (both unpolarized and linearly and circularly polarized) in the energy range up to $730\,MeV$ (High Energy Photon Line-Line A); the second beam line for experiments with electrons with the same maximal energy (Electron Beam Line-Line C). The third beam line is proposed to be constructed in the Lens Hall of the linac $LU-2\,GeV$ and it is aimed on experiments with real tagged photons (also both unpolarized and linearly and circularly polarized) in low energy range, up to $490\,MeV$ (Low Energy Photon Line-Line B). The linearly polarized photon beam on both photon beam lines is planned to obtain using the CB process of the electrons in diamond crystals.

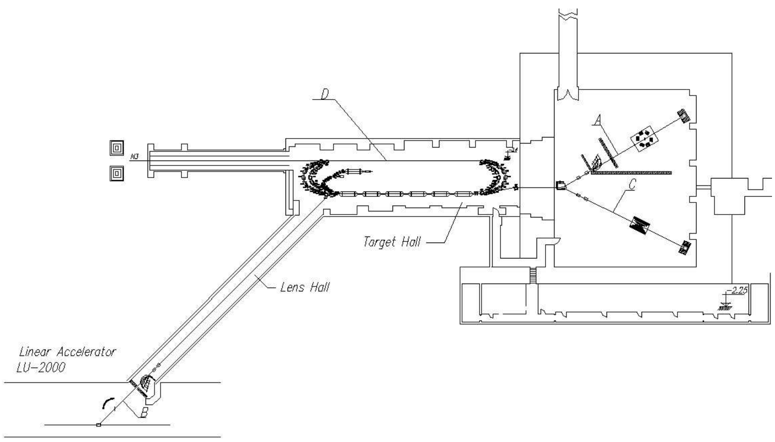

Fig.1. *General scheme of the SALO facility with beam lines. A-High Energy Photon Line, B-Low Energy Photon Line, C-Electron Beam Line, D-Free Electron Laser Line*

For estimation of the possible CB beam parameters, intensity and polarization and their dependence on crystal orientation for proposed photon beam lines the relevant calculations were made with using analytical code developed by P.Grabmayr and co-workers [12] on the base of Born approximation [6, 7, 8]. At present this is the most perfect program for the CB characteristics calculation which allow to take into account most of experimental factors with sufficient accuracy: electron beam size, energy and angular divergence, multiple scattering in the crystal, photon beam collimation. In comparison with previous calculations some improvements were made in this program both in the CB formula [7] and in procedure of the experimental factors taking into account. Improvements in the formula included new parameterizations of the carbon form factor, the angular distributions of the coherent and incoherent electron-nuclear contributions and the electron-electron bremsstrahlung. For the experimental factors taking into account the following assumption were made. The beam angular distribution and electron beam distribution function due to multiple Coulomb scattering were assumed to be of two-dimensional Gaussian shape. The electron beam distribution within spot on the target and electron beam energy spread around the nominal energy E_0 were also approximated by Gaussians. With such approach the expected calculated the CB intensity results from folding of all experimental effects weighted with the above distributions and as a result the 8-fold integral was appeared.

For calculation this 8-fold integral a Monte Carlo method was used but it takes sufficiently much time. For acceleration the CB calculation an analytical approach was developed in which: (i) all two-dimensional distributions were assumed to be Gaussian in shape with azimuthal symmetry; (ii) the overall electron angular distribution was obtained by folding the electron beam multiple scattering and initial angular divergence distributions; (iii) for the collimated photon spectra calculation the effects of the beam size, divergence and multiple scattering were also combined into one Gaussian angular distribution with relevant parameters. This code was tested and well described the CB beam parameters obtained at the Mainz facility for $E_0 = 855\,MeV$. A comparison of the analytical and Monte Carlo codes calculations has shown that they gave almost identical results.

Using analytical code [12] we made calculations of the CB beam spectra and polarization for diamond crystal with thickness $0.1\,mm$. The crystal orientation is determined by two angles, θ and α. θ is the angle between electron beam momentum P_0 and crystal axis $b_1 = \langle 100\rangle$,α is the angle between planes (P_0, b_1) and planes (b_1, b_2), where $b_2 = \langle 010\rangle$. The angles θ and α were chosen in a such a way that main contribution to the CB cross section was produced point $(0, 2, \bar{2})$ of the crystal reciprocal lattice. The electron beam energy spread was assumed to be 0.08%, diameter of the electron beam spot on the target was $1\,mm$.

Some calculation results are shown in Fig.2,3 where the polarization P, total intensity $I_{sum} = I_{coh} + I_{in}$, and coherent effect β of the CB are presented. Coherent effect is determined by the relation

$$\beta = \frac{I_{coh} + I_{in}}{I_{coh}},$$

I_{coh} and I_{in} are the intensity of the radiation per one electron and is determined as $I_{coh,in} = (E_\gamma/\sigma_0)(d\sigma_{coh,in}/dE_\gamma)$, where $\sigma_0 = 0.5794 \cdot 10^{-27}\,Z^2 cm^2$. In Fig.3 it is shown calculations for initial electron energy $E_0 = 730$ and $490\,MeV$ and collimation angles in the interval from $\theta_c \approx 0.5\,\theta_\gamma$ and up to $1.9\,\theta_\gamma$ ($\theta_\gamma = mc^2/E_0$, where m is the electron mass). The orientation angle's values were chosen so that energy of the CB peak was $E^p_\gamma = 170.5\,MeV$ (relative photon energy $X = E_\gamma/E_0 = 0.23$), but due to multiple scattering of the electron beam the real peak position is shifted to slightly lower energy. One can see that at these conditions for beam Line A at relative energy $X \sim 0.2$, we may obtain essentially high polarization ($P_\gamma \sim 55\%$) at the CB peak and coherent effect $\beta \sim 2.5 - 3$ even without any collimation of the photon beam. At the strong collimation ($\theta_c \approx 0.47$) the polarization is increased up to $\sim 75\%$ and coherent effect become two times more but the total intensity in the CB maximum becomes six times less.

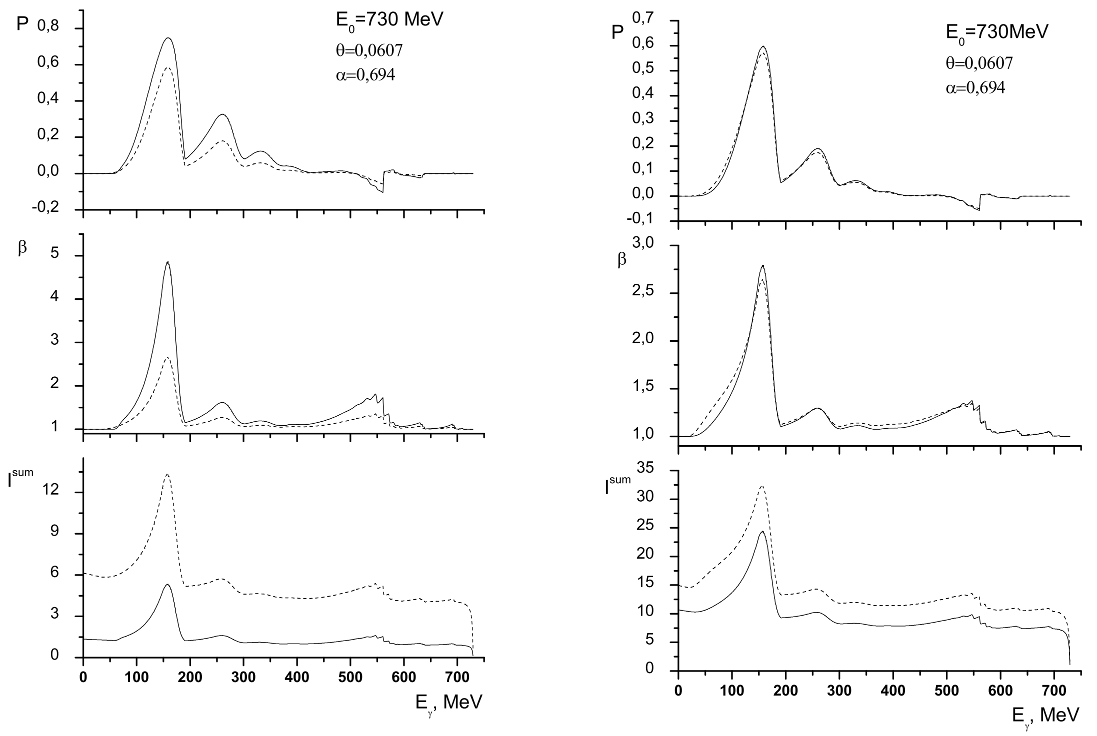

Fig.2. *Polarization, coherent effect and full intensity of the CB for collimation angles: left panel - $\theta_c = 0.47\,\theta_\gamma$ (solid line,) and $0.71\,\theta_\gamma$ (dashed line); right panel - $\theta_c = 1.19\,\theta_\gamma$ (solid line) and $1.9\,\theta_\gamma$ (dashed line)*

Calculations for more high peak energies $X \sim 0.41$ are presented in Fig. 3 for $E_0 = 730$ and $490\,MeV$ and some collimation angles in interval from $\theta_c \sim 0.5$ and up to $\theta_c \sim \theta_\gamma$. We can see that for $E_0 = 730\,MeV$ polarization and coherent effect are changed in the range $P \sim 0.4 - 0.6$ and $\beta \sim 2 - 3$ and they are $P \sim 0.35$ and $\beta \sim 1.7$ for $E_0 = 490\,MeV$. From previous experience it is known that the CB beam can be used in experiments if the polarization and coherent effect are no less than $P_\gamma \sim 30\%$ and $\beta \sim 1.5$, so the CB beam parameters for this photon energy are also good enough for using in polarized experiments.

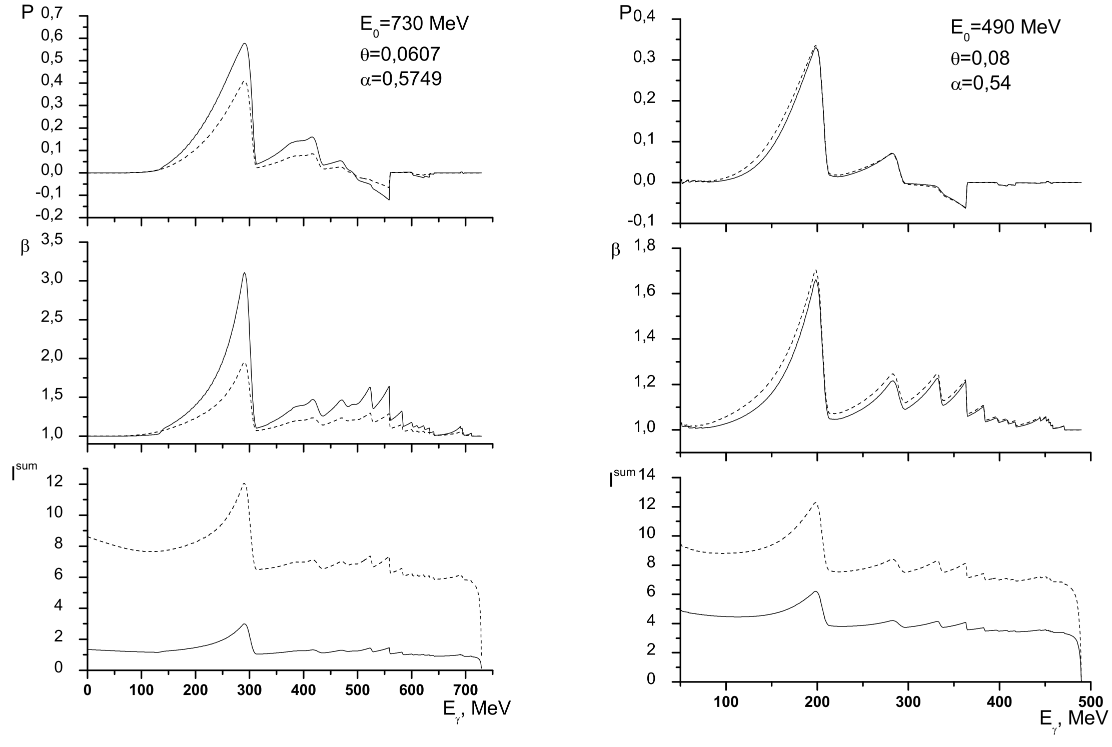

Fig.3. *Polarization, coherent effect and full intensity of the CB.*
Left panel: initial electron energy $E_0 = 730\,MeV$*, collimation angles* $\theta_c = 0.47\,\theta_\gamma$ *(solid line),* $0.95\,\theta_\gamma$ *(dashed line);*
right panel: $E_0 = 490\,MeV$*,* $\theta_c = 0.63\,\theta_\gamma$ *(solid line) and* $1.12\,\theta_\gamma$ *(dashed line)*

In more detail the CB parameters collimation dependence for is shown on Fig.4 for initial electron energies $E_0 = 730\,MeV$ and $490\,MeV$ and the CB peak energy $X \approx 0.23$. It demonstrates fast increasing of the polarization and coherent effect values with decreasing collimation angle, especially for angles $\theta_c \leq 0.8\,\theta_\gamma$ where these parameters can reach values $P \sim 80\%$ and $\beta \sim 5-6$ for strong photon collimation. On other hand polarization and coherent effect do not practically change for collimation angles $\theta_c > 0.8\,\theta_\gamma$, and at the same time the CB intensity is somewhat increased with the collimation angle increasing. So it is more preferable to use more collimations angle if there are no any additional restrictions.

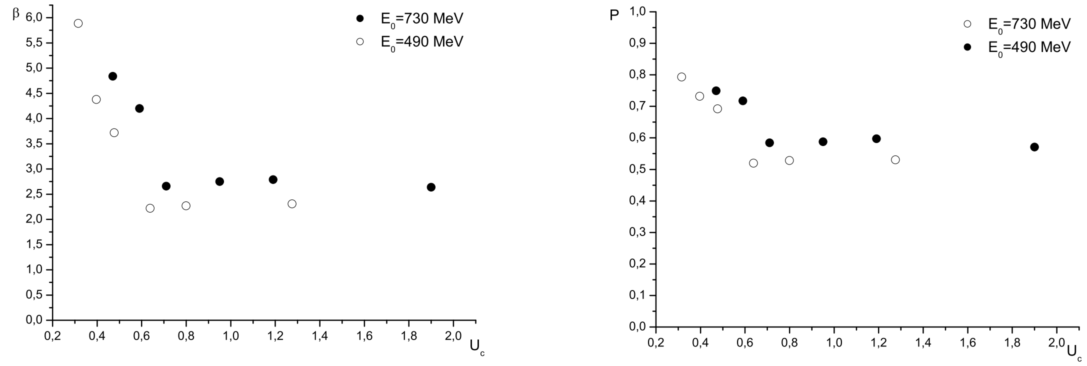

Fig.4. *Coherent effect and polarization dependencies from collimation angle for initial electron energy* $E_0 = 730\,MeV$ *and peak photon energy* $170\,MeV$ *and for initial electron energy* $E_0 = 490\,MeV$ *and peak photon energy* $100\,MeV$

The important characteristic of the polarized beam is the energy range where the beam could be applied for photonuclear investigations. In Fig.5 it is presented the results of the energy dependence calculations of the coherent effect and polarization for electron beam energies $E_0 = 490\,MeV$ and $730\,MeV$, which will be acceptable on SALO photon beam lines. It is seen that the values of the coherent effect and polarization decrease from $\beta \approx 3.6$ and $P_\gamma \approx 70\%$ at $E_\gamma \sim 100\,MeV$ up to $\beta \approx 1.6$ and $P_\gamma \approx 25\%$ at $E_\gamma \sim 400\,MeV$ for initial electron energy $730\,MeV$ and from $\beta \approx 2.8$ and $P_\gamma \approx 60\%$ at $E_\gamma \sim 50\,MeV$ and up to $\beta \approx 1.5$ and $P_\gamma \approx 23\%$ at $E_\gamma \approx 250\,MeV$ for initial electron energy $E_0 = 490\,MeV$. The calculations demonstrate that acceptable energy ranges for nuclear physic investigation with linearly polarized photons for Line A is extended up to photon energy $E_\gamma \sim 400\,MeV$ at collimation $\theta_c \sim \theta_\gamma$ and could be increased up to $450\,MeV$ under more strong collimation. That will allow one to study pair pion photoproduction on nucleon and nuclei near threshold with polarized photons. The acceptable interval for Line B, where experiments with polarized photon are also planned, is extended up to $E_\gamma \approx 250\,MeV$ that is it enough to cover the experiments on single pion photoproduction at threshold energy range.

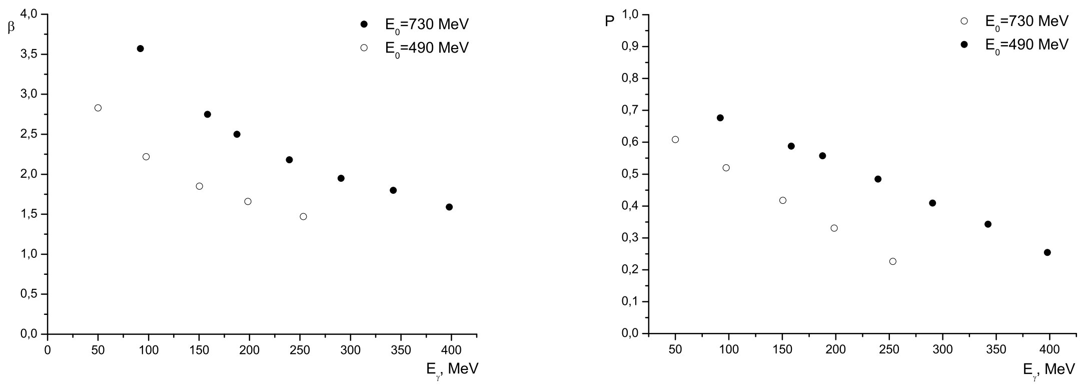

Fig.5. *Coherent effect and polarization dependencies from peak energy for initial electron energy* $E_0 = 730\,MeV$ *and collimation angle* $\theta_c = 0.95\,\theta_\gamma$ *, and* $E_0 = 490\,MeV$ *and collimation angle* $\theta_c = 0.63\,\theta_\gamma$

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REFERENCES

1. [NuPECC 04] NuPECC Long Range Plan 2004: Perspectives for Nuclear Physics Research in Europe in the Coming Decade and Beyond. Edited by Muhsin Harakeh, Daniel Guerreau, Walter Henning, Mark Huyse, Helmut Leeb, Karsten Riisager, Gerard van der Steenhoven and Gabriele-Elisabeth Korner. Sponsored by CEC under Contract Nr. HPRI-CT-1999-40004.

2. Y.M. Arkatov et al. Basic accelerating facility NSC KIPT by nuclear physics and high energies physics. The "SALO" project. *Kharkov: NSC KIPT*, 2004. (in Russian).

3. Y.M. Arkatov et al. "SALO" project. *Kharkov: NSC KIPT*, 2005, p.104.

4. V.B. Ganenko et al. Perspective directions of experimental researches on fundamental physics at intermediate energies on the proposed $730\,MeV$ linear electron accelerator NSC KIPT // *Problems of Atomic Science and Technology.* 2004, N5, (41), p.164-168.

5. Funadmental and applied researches on linear accelerator-reciculator of electrons with energy up to $730\,MeV$. Project SALO. *Kharkov: NSC KIPT,* 2006, p.116.

6. G. Diambrini. High energy bremsstrahlung and electron pair production in thin crystals // *Nuclear Physics Investigations. Rev. Mod. Phys.* 1968, v.40, p.611-631,

7. U. Timm. Coherent bremsstrahlung of electrons in crystals // *Fortschr. der Phys.*, 1969, v.17, p.765-768.

8. M.L.Ter-Mikaelian. *High-Energy Electromagnetic Processes in Condensed Media*, Wiley, New York, 1972.

9. G.D. Kovalenko et al. Topics in Current Physics 38: Coherent Radiation Sources. *Coherent Bremsstrachlung-Experiment*, Springer-Verlag Berlin Heidelberg, 1985, p.33-60.

10. D. Lohmann et al. // *Nucl. Instr. and Meth.* 1994, A343, p.494.

11. R.T. Jones. Intense beams of polarised and nearly monochromatic photons from coherent bremsstrahlung // *Workshop on Physics with 8+ GeV Photons*, Bloomington, 1997, July 14-15, Indiana University, 1998.

12. F.A. Natter, P. Grabmayr, T. Helh et al. Monte Carlo Simulation and Analytical Calculation of Coherent Bremsstrahlung and its Polarization // *Nucl. Instr. and Meth.* 2003, B211, p.465-486.

ЛИНЕЙНО ПОЛЯРИЗОВАННЫЙ ФОТОННЫЙ ПУЧОК ДЛЯ ФОТОЯДЕРНЫХ ИССЛЕДОВАНИЙ НА НОВОЙ УСТАНОВКЕ ННЦ ХФТИ

В.Б. Ганенко, Г.А. Ващенко, Д.Д. Бурдейный

Рассчитаны спектры интенсивности и поляризации когерентного тормозного излучения для проектируемой установки ННЦ ХФТИ (проект SALO) для двух возможных каналов вывода электронного пучка из ускорителя с максимальными энергиями пучка 490 и 730 МэВ. Показано, что при определенных условиях формирования возможно получение пучков КТИ с интенсивностью и поляризацией, достаточными для проведения экспериментальных исследований в интервале энергий фотонов до 400 МэВ на пучковой линии с максимальной энергией электронов до 730 МэВ, и в интервале до 250 МэВ на пучковой линии с максимальной энергией электронов до 490 МэВ.

ЛІНІЙНО ПОЛЯРИЗОВАНИЙ ФОТОННИЙ ПУЧОК ДЛЯ ФОТОЯДЕРНИХ ДОСЛІДЖЕНЬ НА НОВОМУ ПРИСТРОЇ ННЦ ХФТІ

В.Б. Ганенко, Г.А. Ващенко, Д.Д. Бурдейний

Розраховані спектри інтенсивності і поляризації когерентного гальмівного випромінювання для проектованої установки ННЦ ХФТІ (проект SALO) для двох можливих каналів виведення електронного пучка з прискорювача з максимальними енергіями пучка 490 і 730 МеВ. Показано, що за певних умов формування можливе отримання пучків КГВ з інтенсивністю і поляризацією, достатніми для проведення експериментальних досліджень в інтервалі енергій фотонів до 400 МеВ на пучковій лінії з максимальною енергією електронів до 730 МеВ, і в інтервалі до 250 МеВ на пучковій лінії з максимальною енергією електронів до 490 МеВ.