https://doi.org/10.46813/2023-148-106

LOW INTENSITY BEAMS OF ELECTRONS AND POSITRONS IN THE ENERGY RANGE UP TO 100 MeV AT IHEPNP FACILITY

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The article considers possible characteristics of low-intensity secondary positron and electron beams, which can be obtained using an electron accelerator with energy of ~100 MeV and average current of some μA. Preliminary simulation shows that using a tungsten converter of $2X_0$ thick and collimation of secondary particles beam, such accelerator allows one to get electron and positron secondary beams with energy of ~ 5…70 MeV, intensity of $\sim 10^{-6-8}$ from the primary electron beam intensity, and energy spread of about some percent. Such low-intensity beams can be used for researches in the field of interaction of radiation with amorphous substances and crystals, testing detectors and scintillation materials.

PACS: 29.20.-c

INTRODUCTION

In work [1], the possibility of creating an experimental facility at the IHEPNP NSC KIPT has been discussed, for studying the interaction of radiation with amorphous substances and crystals, as well as for research in the field of nuclear and applied physics.

The facility was planned to be built using the existing experimental infrastructure and a linear electron accelerator with a maximal energy of E_0~100 MeV. It should include two beam lines. One line (line-1) will be used for experiments with high-intensity electron and photon beams, including linearly polarized ones. The other beam line (line-2) will be used for experiments with low intensity beams of electrons and positrons, $\sim 1…10^3$ particles per pulse of the accelerator.

According to preliminary estimates [1], at electron beam with energy of E_0=100 MeV and a current of 1 μA, the yield of secondary electrons and positrons from a tungsten converter with a thickness of about $2X_0$ will be sufficient to obtain the electron or positron beams of the above indicated intensity in energy range of 10...80 MeV with energy resolution ~1…2 MeV.

In this article, the possible characteristics of these low-intensity beams are discussed in more detail.

1. THE LOW-INTENSITY BEAM LINE

Scheme of the beam lines of the facility is shown in Fig. 1. Secondary particles (electrons and positrons) for formation of the low-intensity electron or positron beams are generated by interaction of the primary electron (or photon) beam with a heavy metal radiator (9) of several radiation lengths thick. The resulting secondary particles are captured by a magnet (10) into the beam line-2, on which the beam formation and control elements, collimators (21, 22, 27) and beam position monitors (23, 26, 28) are located. The magnet (24) directs the beam through the collimator (27) into experimental area onto the goniometer (29). The beam position on the collimator is controlled by the monitor (26), and its size and position in front of the crystal is controlled by the monitor (28). After passing through the goniometer, the beam is deflected by the magnet (30) and intensity of the beam is registered by the detector (31). The produced gamma-quanta pass (if it is necessary) through a collimator (32) and are registered by a photon detector (33). It should be noted that part of the beam line-2 from the first bending magnet to the Faraday cup (25) also can be used to deflect and absorb the electron beam in the course of experiments with high-intensity photon beams on line-1.

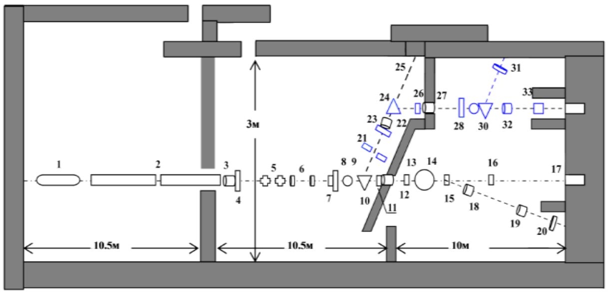
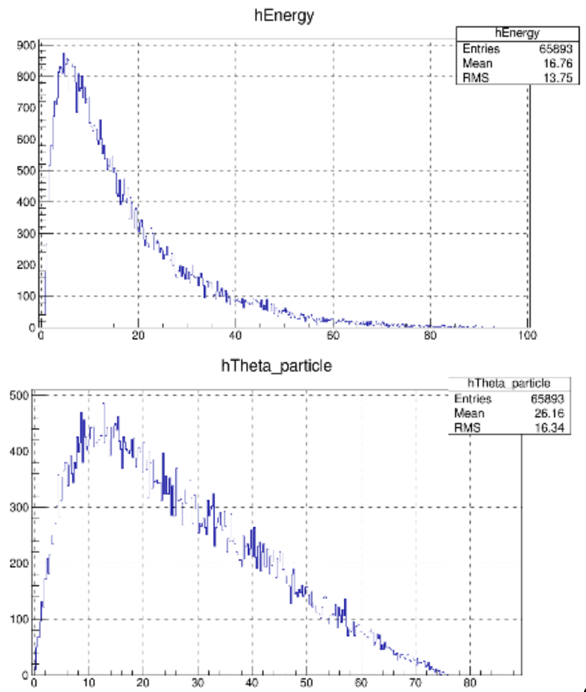


Fig. 1. Scheme of the experimental set-up (from [1]): 1 – injector; 2 – accelerating sections; 3 – collimator; 4 – monitor of electron beam position and current; 5 – quadrupole lenses; 6 – two pairs of beam correctors; 7 – secondary emission monitor; 8 – monitor of the electron beam position on the photon radiator (crystal); 9 – goniometer or amorphous radiator for production photon beam for beam line-1 (or convertor for low intensity beams production); 10 – the first bending magnet; 11 – monitor of the photon beam position on the collimator; 12 – photon collimator; 13 – monitor of the photon beam position on the nuclear target; 14 – nuclear target and detecting equipment; 15 – photon scatterer; 16 – ionization chamber; 17 – quantometer (or Faraday cup); 18 and 19 – collimators of the Compton scattering channel; 20 – detector of the scattered photons; 21, 22, 27 – collimators; 23, 26, 28 – monitors of the beam position; 24 – the second bending magnet; 25 – cylinder Faraday; 29 – goniometer; 30 – cleaning magnet; 31 – detector of the particles; 32 – photon collimator; 33 – photon detector

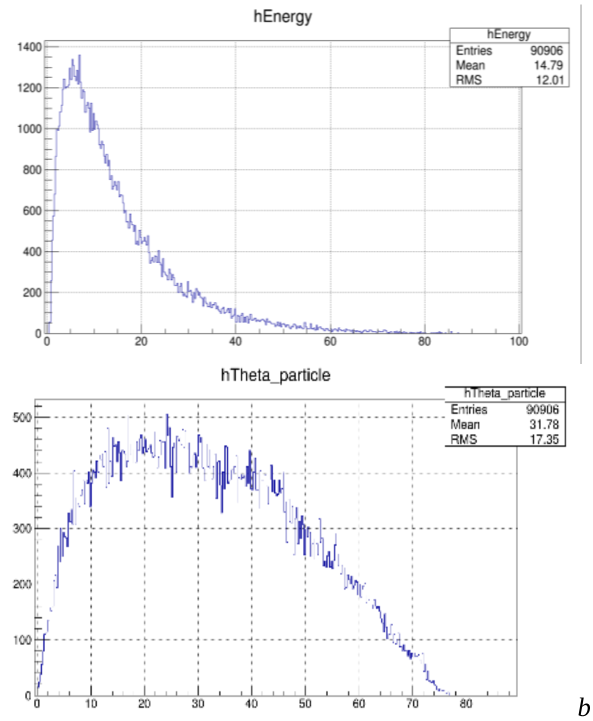
For a more detail study of the possibilities of forming the required parameters of the low-intensity beams and evaluating their characteristics, using the GEANT-4 package, a program was developed to simulate process of the production of electrons and positrons in the converter and their passage through the beam line-2.

2. SPECTRAL AND ANGULAR DISTRIBUTIONS OF POSITRONS EMITTED FROM THE CONVERTER

The spectral and angular distributions of secondary particles, electrons and positrons, produced in the course of interaction of an electron beam with a tungsten converter of L = 3.6, 5.4, 7.2, 9, and 10.8 mm thick have been calculated. These thicknesses correspond to X_0, $1.5X_0$, $2X_0$, $2.5X_0$, and $3X_0$ radiation lengths respectively. To reduce the effect of secondary particles multiple scattering in the converter material, it was chosen to have a cylindrical shape of d = 3.6 mm ($1X_0$) in diameter. Fig. 2 shows results of the simulation of energy and angular distributions of positrons, produced by E_0 = 100 MeV electron beam in the converter of X_0, $2X_0$, and $3X_0$ thick.



a



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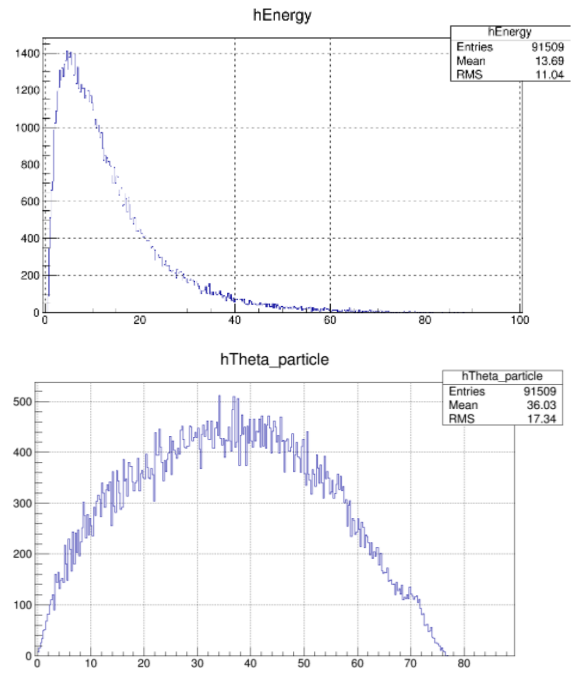

c

Fig. 2. Energy (top) and angular (bottom) distributions of the positrons emitted from a tungsten converter with thickness L=3.6 mm (X_0). Electron beam energy is E_0=100 MeV (a). The same for converter of 7.2 mm ($2X_0$) (b). The same for converter of 10.8 mm ($3X_0$) (c)

It can be seen that the positron spectra are practically independent on the converter thickness. They have a maximum at the energy E_{e+}~5…7 MeV and decrease rapidly with increasing energy. The main yield falls on positrons with energies E_{e+}≤40 MeV. On the contrary, the angular distributions of positrons depend on the thickness of the converter. For thicknesses L = 3.6 and 5.4 mm, they have a maximum at angles of 10…15° degrees and rapidly decrease with increasing angle. But with a larger thickness, L = 7.2, 9, and 10.2 mm, the maximum becomes wider and shifts to the region of larger angles, and the angular distribution becomes more symmetrical. The total positron yield slightly increases with thickness up to ~1.5…$2X_0$.

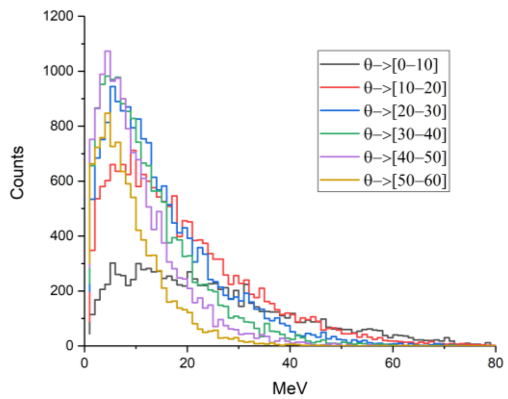

Fig. 3. Spectra of positrons emitted in angular intervals of 10^0 wide, shown in the inset. Converter thickness is L=7.2 mm ($2X_0$)

More informative for the practical formation of a low-intensity beam are the spectral-angular characteristics of the emitted positrons, shown in Fig. 3. It can be seen that the shape of the spectra depends on the positron emission angle. At small angles, $\Delta\theta_1$=0…10°, the spectrum does not have a clear maximum. The yield of low-energy positrons with $E_{e+}\leq$ 5 MeV drops strongly due to absorption in the converter material. But the yield of positrons with higher energies, E_{e+}>15 MeV, decrease more slowly with increasing energy and, therefore, remains noticeable at energies up to E_{e+}~70 MeV. With an increase in the emission angle, a more distinct maximum is formed in the spectrum, the energy of which decreases from $E_{e+}\approx$10 MeV at $\Delta\theta_2$=10…20° to $E_{e+}\approx$5 MeV at $\Delta\theta_6$=50…60°, and the spectrum itself narrows due to decrease in the yield of energetic positrons. Based on the spectral characteristics, positrons emitted in the range of angles $\Delta\theta_2$=10…20° and $\Delta\theta_3$=20…30° are the most optimal for the formation of low-intensity beams with energies $E_{e+}\geq$30 MeV.

3. EXPECTED CHARACTERISTICS OF LOW-INTENSITY POSITRON BEAM

Characteristics of the low-intensity positron beam, that can be obtained at the facility, were obtained by simulation. At the first stage, for simplicity, only the main elements of beam line-2 were included: the first (10) and second (24) bending magnets, as well as two collimators (21, 22) (see Fig. 1). Scheme of the simulation is shown in Fig. 4. The axis of the beam line-2 between the bending magnets is directed under angle of 45° to the axis of the primary electron beam. The distance between the magnets is about 180 cm. The tungsten convertor of $2X_0$ thick, in which the secondary particles are produced, is located on the axis of the primary electron beam from the linac, on the distance of ~47 cm before the first bending magnet, and was not shown in the Fig. 4.

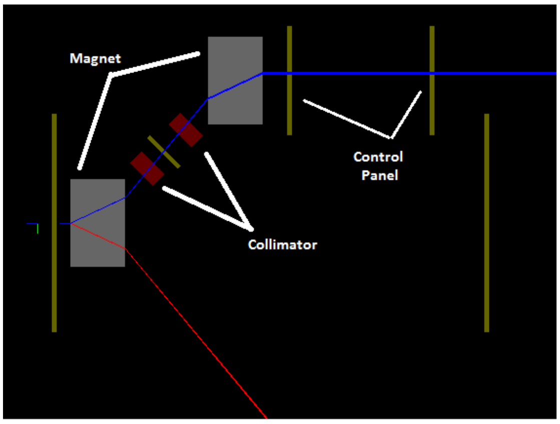

Fig. 4. Scheme of the simulation. See text for details

To simulate the formation of a positron beam, particles emitted from the converter in the interval of angles $\Delta\theta_3$=20…30° were selected, and directed to the first bending magnet. For simplicity, the bending magnets were represented as a rectangular region of a uniform magnetic field with length of 50 cm. The magnitude of the magnetic field of both magnets was chosen such as to direct positrons with a given energy (in our case $E_{e+}\approx$30 MeV) along the beam-2 axis through the collimators onto the goniometer target.

The first collimator was located on the beam line-2 at exit from the first magnet, the second before the beam entering the second magnet. The length of the collimators was 15 cm. The angular and energy distributions of the positron beam, as well as other additional information, were recorded in certain places along the beam path, designated in Fig. 4 as control panels (№ 1, 2, 3, 4, 5). Fig. 5 shows the spectra of the positron beam that passed through the first magnet and the first collimator (recorded on the panel № 2) depending on the diameter of the collimator hole.

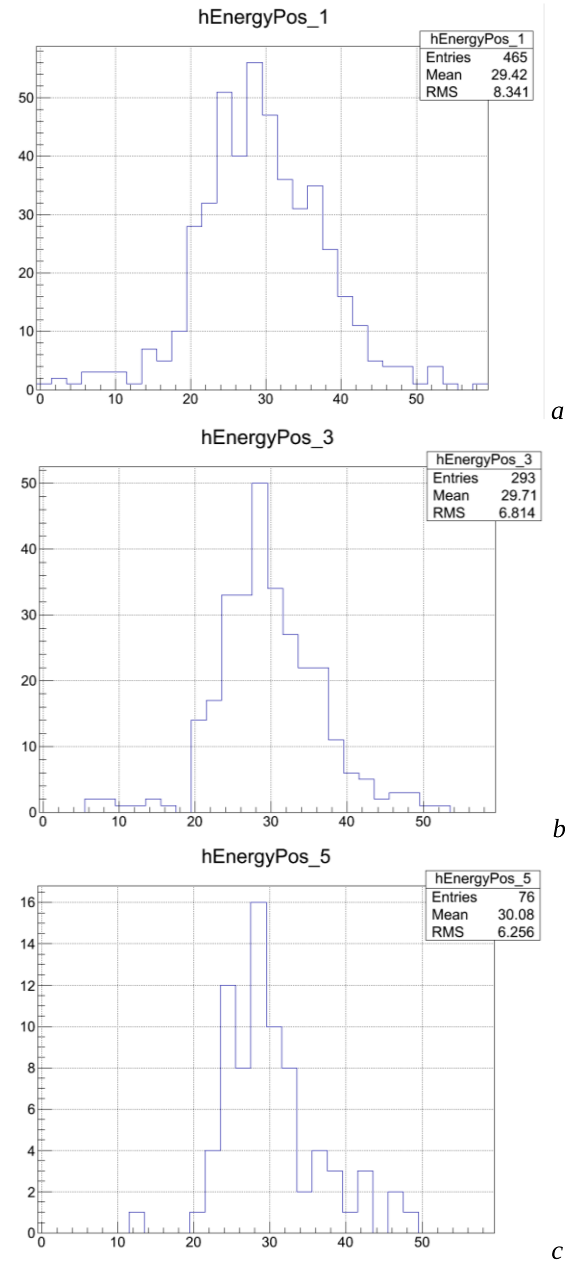

Fig. 5. Spectra of positron beam after passing through the first collimator of 50 mm in diameter. The same for collimator of 20 mm (b). The same for collimator of 10 mm (c)

Simulation shows that the first collimator with a hole of 10 mm in diameter makes it possible to obtain a positron beam with an energy of $E_{e+}\approx$30 MeV and an energy spread of $\Delta E_{e+}\approx$8.4 MeV (FWHM). The similar spectra after passing the beam through the second collimator (fixed on panel № 3) are shown in Fig. 6.

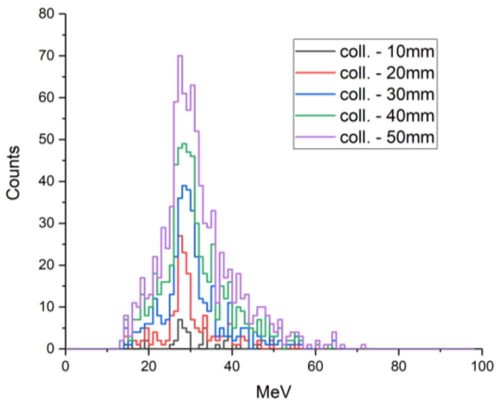

Fig. 6. Spectra of positron beam after passing through the second collimator. Diameter of the second collimator hole is presented in the inset

One can see that after the second collimator with a collimator hole 10 mm in diameter, it is possible to obtain positron beam with energy E_{e+}≈30 MeV and energy spread ΔE_{e+}≈2.2 MeV (FWHM) and intensity of $N_{e+}\approx 8.0\cdot 10^{-6}N_0$, where N_0 is the number of electrons incident on the converter. For the primary electron beam current ~1 μA (N_0~$6\cdot 10^{12}e^-$/s) the expected positron beam intensity can reach N_{e+}~$5\cdot 10^7e^+$/s. Thus, it is possible to significantly improve the energy resolution of the beam due to stronger collimation and to use less intense electron beam, which improves the radiation situation in the experimental hall.

For the energy of the primary beam E_0=60 MeV, the expected intensity of the positron beam is 4-5 times less. The expected energy spread and intensity of the positron beam in depending on the second collimator diameter are presented in the Table.

SUMMARY

The possible characteristics of the low-intensity positron (and electron) beams which can be obtained at the IHEPNP facility [1] have been considered by simulation, using a GEANT-4 package.

The spectral and angular distributions of positrons, produced at interaction of 100 MeV electron beam with a tungsten converter of L = 3.6, 5.4, 7.2, 9, and 10.8 mm thick have been calculated. Results of the preliminary simulation show that, firstly, optimal thickness of the tungsten converter for the secondary positron generation is about $2X_0$ (7.2 mm). Secondly, it is possible to obtain low intensity beams with energies of ~10…70 MeV.

Simulation of the passage of the positron beam with energy E_{e+}≈30 MeV through the beam line shows that, using a collimator with a hole of 10 mm in diameter, it is possible to obtain energy spread of the beam ~7% and intensity of ~10^{-6} of the intensity of the primary electron beam. The energy spread can be improved by using the collimators of smaller diameter.

In conclusion, it should be noted that due to the destruction of the infrastructure of the experimental facility of the IHEPNP NSC KIPT, described in [1], as a result of military operations, such low-intensity electron and positron beams can be created on the basis of the currently operating electron accelerator LUE-40 NSC KIPT [2], which provides a maximum electron beam energy of 85 MeV and has the necessary infrastructure.

Energy spread and intensity of the positron beam with energy E_{e+}≈30 MeV after passing through the second collimator, N_0 is the intensity of the electron beam incident on the converter

Diameter of the second collimator hole, mm	N_{e+}/N_0	ΔE_{e+}, MeV
10	$8.0\cdot 10^{-6}$	2.2
20	$3.4\cdot 10^{-5}$	3.0
30	$7.5\cdot 10^{-5}$	5.3
40	$1.2\cdot 10^{-4}$	~7
50	$1.8\cdot 10^{-4}$	~8

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Article received 21.07.2023

ПУЧКИ НИЗЬКОЇ ІНТЕНСИВНОСТІ ЕЛЕКТРОНІВ ТА ПОЗИТРОНІВ У ДІАПАЗОНІ ЕНЕРГІЙ ДО 100 МеВ НА УСТАНОВЦІ ІФВЕЯФ

Д.Д. Бурдейний, В.Б. Ганенко

Розглядаються можливі характеристики низькоінтенсивних вторинних позитронних і електронних пучків, які можна отримати за допомогою прискорювача електронів з енергією ~100 МеВ і середнім струмом кілька мікроампер. Попереднє моделювання показує, що за допомогою вольфрамового конвертера товщиною $2X_0$ і колімації пучка вторинних частинок такий прискорювач дозволяє отримати вторинні пучки електронів і позитронів з енергією ~5…70 МеВ, інтенсивністю ~10^{-6-8} від інтенсивності пучка первинних електронів та енергетичного розкиду приблизно кілька відсотків. Такі низькоінтенсивні пучки можуть бути використані для досліджень в області взаємодії випромінювання з аморфними речовинами і кристалами, тестування детекторів і сцинтиляційних матеріалів.