Positron Source Employing Crystalline Radiator.

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Abstract

The factors that determine the efficiency of the positron source based on coherent electron beam interaction with a crystalline radiator are studied. It is shown that the dependence of positron yield on the atomic number of radiator material changes sharply when the primary electron energy increases from some GeV to tens GeV.

1. INTRODUCTION

The crystalline radiator, in which relativistic electron beam energy is transformed to that of gamma radiation, permits one to increase essentially the efficiency of positron source based on the cascade process $e^- \rightarrow \gamma \rightarrow e^{\pm}$ [1,2].

The choice of radiator materials is one of the most important problems that this topical trend of accelerator physics faces. The aim of this work is to research theoretically, at various energies of the primary electron beam, how the positron yield depends on the atomic number of radiator material Z.

The version of the source we have considered consists of the separate crystalline radiator and amorphous converter. The gamma quanta emitted in the radiator are transformed into e+, e-pair in the converter. This one has the thickness small enough for the electromagnetic shower tô be neglected.

2. CALCULATION METHOD

To calculate the converter the physical model of positron production process has been developed. This one allows for photon absorption in the matter, multiple scattering and energy losses of produced positrons. The created computer program has small running time and gives the results closed to those obtained by means of EGS4 code, which is generally used for positron source calculation [3].

The radiator calculation was performed by means of the method developed in our pervious works. This approach allows one to calculate the characteristics of radiation emitted by a relativistic electron in an external field at any value of the parameter describing non dipole character of radiation [4]. Its efficiency was proven previously, when new interference and polarization effects arising during ultra relativistic electron interaction with a crystal were studied [5,6]. When calculating the photon spectrum at the radiator exit, we took into account quantum recoil effect at radiation, photon absorption, multiple scattering and energy losses of radiating electrons.

.The positron yield dependence on the radiator thickness was studied at two values of the primary electron energy: E_b=2 GeV and E_b=20 GeV. As radiator materials, we took silicon and germanium crystals oriented on <111> axis and tungsten oriented on <100> axis.

The analysis we had performed proved the positron yield to depend weakly on the converter materials. So we considered only the tungsten converter with thickness of half radiation length.

3. RESULTS AND DISCUSSION

The yield of positron having energies from 5 MeV to 50 Mev and angle divergence $\Delta\vartheta \leq 10^\circ$ has been calculated. The results are presented at Fig. 1 and Fig. 2.

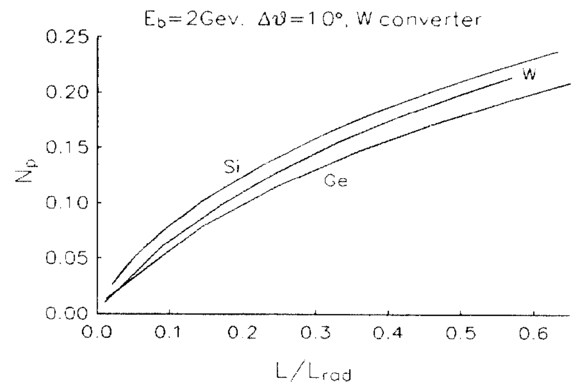

Figure 1. The positron yield versus radiator thickness. The primary electron energy is 2 GeV. The tungsten converter with thickness of half radiation length.

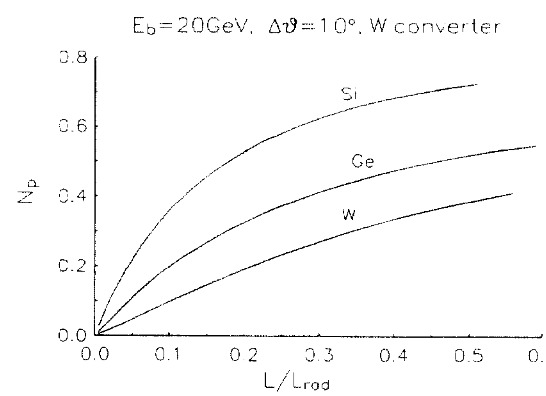

Figure 2. The positron yield versus radiator thickness. Theprimary electron energy is 20 GeV. The tungsten converter with thickness of half radiation length.

The curve shows the positron yield per an incident electron versus radiator thickness expressed in the units of the radiation length.

The reported result shows that the character of the Z-dependence of the positron yield changes sharply when the primary electron energy increases from 2 GeV to 20 GeV.

To explain this effect let us make the note that the radiation process has essentially non dipole character for al three crystals at electron energy about 20 GeV. The typical radiation frequency ω_{ch}, which determines the spectrum width $\Delta\omega$, is proportional to the gradient of the atomic string averaged potential

$$\Delta\omega \sim \omega_{ch}\,\omega_{ch} \sim E^2 Z^{4/3}.$$

It means that when Z increases, the spectrum $\frac{dE}{d\omega}$ enlarges to the side of higher frequency values. Let us take into account now that the number of created positrons is proportional to the following expression

$$N \sim \int d\omega\, \sigma(\omega) \frac{1}{\omega}\frac{dE}{d\omega}, \quad (1)$$

where $\sigma(\omega)$ is the cross section of pair creation by the photon with energy ω. It is easy to see that the cutting factor $\frac{1}{\omega}$ depresses the contribution of the processes with high ω values. So the cause why the efficiency of the crystalline radiator decreases with Z increase is the mentioned effect of non dipole radiation spectrum enlarging.

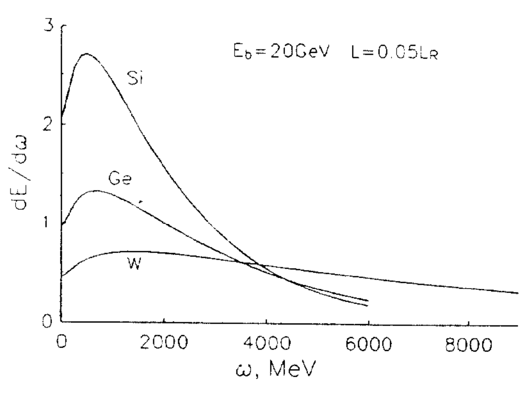

Figure 3. The radiation spectra emitted in radiators with the thickness of 0.05 radiation length

Let us note the significance of radiation electron energy losses. When the crystal thickness L increases, these make the spectra $\frac{dE}{d\omega}$ narrow effectively and decrease difference among the spectra calculated for various Z (See Fig. 3 and Fig. 4) This effect accounts for decreasing difference among the curves on Fig, 2 when the thickness L gets larger.

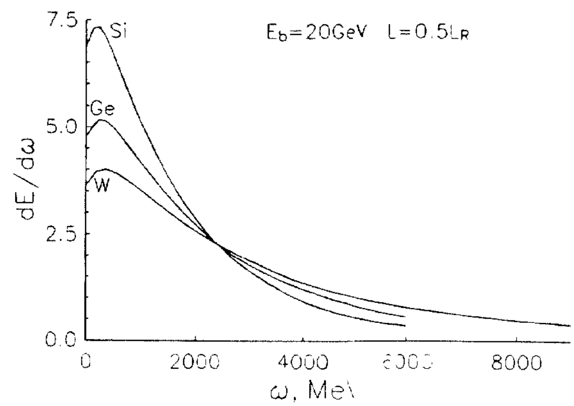

Figure 4. The radiation spectra emitted in radiators with the thickness of 0,5 radiation length

Let us turn ourselves to the analysis of positron production by the electrons with 2 GeV energy. In this energy range, radiation emitted in silicon and germanium has dipole nature and has the rather narrow spectrum $\frac{dE}{d\omega}$ concentrated in the region of small $\omega << E$. The same statement is valid for tungsten if the orientation angle between an electron momentum and a crystal string axis satisfies the condition $\psi \geq \psi_C$, ψ_C being the axial-channeling critical angle. As the mean square angle of electron multiple scattering reaches the value about ψ_C at the crystal length about ten microns, the overwhelming part of electrons, in case of the thick crystal we are considering, moves in the orientation angle region $\psi > \psi_C$.

Under such conditions, when the spectra concentrate in the region of small ω, there is only small difference in the effect that the cutting factor $\frac{1}{\omega}$ produce on the integral (1), determining the positron yield. One should have also in mind that the proportion of the radiation intensity and the mean square angle of electron multiple scattering to Z^2 compensates for that of the crystal thickness to the radiation length $L_R \sim Z^{-2}$.

All mentioned above causes the positron yield to depend weakly on the atomic number Z of the radiator material when the energy of the primary electron beam is small and the coherent radiation process has dipole nature.

4. CONCLUSIONS

Thus, the performed analysis has proved that the efficiency of the positron source based on the coherent radiation of a relativistic electron beam in a crystal depends weakly on the atomic number of radiator material at the energy range about some GeV, when the coherent radiation has dipole character.

At the high energy of the primary electron beam, when the coherent radiation has essentially non dipole nature, the source efficiency increases with the atomic number of the crystalline radiator decreasing.

5. REFERENCES

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