INFLUENCE OF MULTIPLE SCATTERING IN TARGET MATERIALS ON ANGULAR DISTRIBUTION OF CHERENKOV RADIATION

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ВЛИЯНИЕ МНОГОКРАТНОГО РАССЕЯНИЯ ЗАРЯЖЕННЫХ ЧАСТИЦ В МАТЕРИАЛЕ МИШЕНИ НА УГЛОВОЕ РАСПРЕДЕЛЕНИЕ ИЗЛУЧЕНИЯ ВАВИЛОВА-ЧЕРЕНКОВА

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Аннотация. *Излучение Вавилова-Черенкова (ИВЧ) может быть использовано для измерения расходимости пучка. В данной работе делается оценка оптимальных толщин плоских мишеней из алмаза и кварца для генерации ИВЧ с минимальным угловым разрешением, при учете многократного рассеяния электронного сгустка в мишени и с учетом дифракционного эффекта.*

Introduction. Cherenkov radiation (ChR) appears when a charged particle moves in a dielectric medium and its velocity is higher than the velocity of light in that medium. In this case, the photons of ChR are emitted at the angle $\theta_{ch} = 1/\beta n$, where β is the ratio of the charged particle velocity to the speed of light, $\beta = \upsilon/c$, n is the refractive index of a medium. One of the most important applications of ChR is the use of such radiation for charged particle bunch diagnostics. In Ref. [1] there was suggested to use ChR for single femtosecond bunches observation in a free electron laser beam. Also ChR can be used for a beam angular divergence investigation. Maximal angular resolution is required for precise diagnostics, which is determined for ChR by two effects: the diffraction and the multiple scattering of electrons in a target medium. It is important to determine the target thickness at what the beam divergence due to multiple scattering will be minimal but diffraction effect leading to the narrowing of the ChR angular distribution will be maximal.

Research methods. In order to measure beam divergence, the scheme presented in Fig.1 is proposed. A relativistic electron moving at speed $\bar{\beta}$ crosses the inclined transparent dielectric plate. The electron excites dipoles in a medium, which radiate photons of ChR. Detector *D* is placed at fixed angle to the charged particle velocity. The target angle equals ψ and for measuring the angular distribution it can vary because Cherenkov angle θ_{ch} depends on the target angle:

$$\theta_{ch} = \psi + \arcsin\left(n \sin\left(\arccos\left(\frac{1}{\beta n}\right) - \psi\right)\right)$$

When calculating the angular distribution of the ChR from electron beam, it can be assumed that the distribution of particles in the beam obeys the Gaussian distribution with dispersion σ^2. Moreover, it is supposed that at the initial moment of time the bunch is monodirected. When the bunch passes through the target, angular distribution will increase with increasing target thickness. In the work we presume that the influence of the multiple scattering in target on ChR is equal to the influence of the bunch with constant divergence that is equal to divergence at half the target thickness.

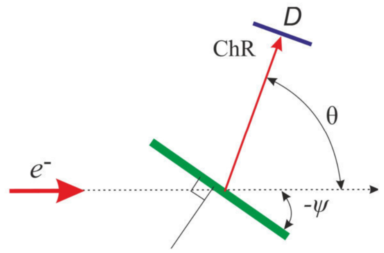

Fig. 1. Cherenkov radiation generation scheme

Knowing the ChR angular distribution generated from a single particle $d^2W/d\omega d\Omega$ (in the work ChR angular distribution was calculated according to the formulas 18.25 and 18.26 Ref. [2]) and integrating over the angular distribution of electron in the bunch, we obtain the expression for the angular distribution of ChR from an electron bunch:

$$\frac{d^2W_b}{d\omega d\Omega}=\int_{-3\sigma}^{3\sigma}\frac{1}{\sqrt{2\pi}\sigma}e^{-\frac{(\psi-\zeta)^2}{2\sigma^2}}\frac{d^2W(\zeta)}{d\omega d\Omega}d\zeta$$

The dispersion is assumed to be equal to the square of the average multiple scattering angle [3]:

$$\sigma^2=\left\langle\theta^2\right\rangle=0.157\frac{Z(Z+1)}{A}\frac{z^2\rho x}{E^2}\ln\left[1.13\cdot10^4\frac{Z^{4/3}}{A}\frac{z^2\rho x}{\beta^2}\right],$$

where x is the target thickness (in our approach x is equal to half the target thickness), Z is the atomic number of the medium, z is the electron's charge, A is the atomic weight, ρ is the density of the medium, E is the electron's full energy.

Results. The approximation described above leads to the curves shown in Fig. 2-4. It is seen from these images that the influence of multiple scattering in diamond after 100 mcm and in quartz after 400 mcm becomes significant.

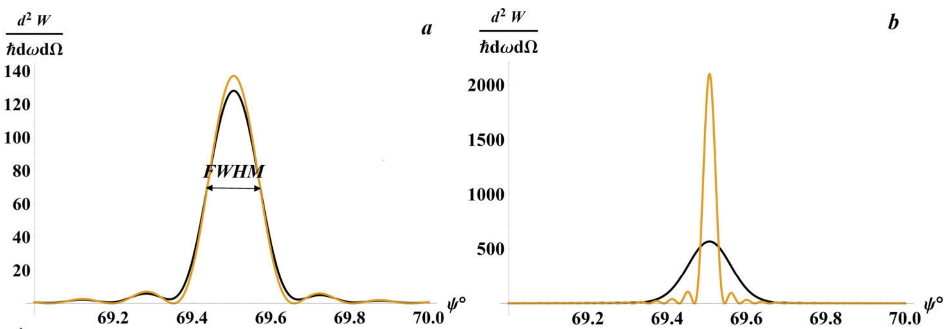

Fig. 2. The angular distribution taking (black line) and not taking (orange line) into account multiple scattering in a diamond target with a thickness of 50 mcm (a) and 200 mcm (b). Simulation options: detector angle $\theta=60^\circ$, the kinetic energy of electrons $T=6$ MeV and refractive index for wavelength $\lambda=500$ nm is $n=2.432$ [4]

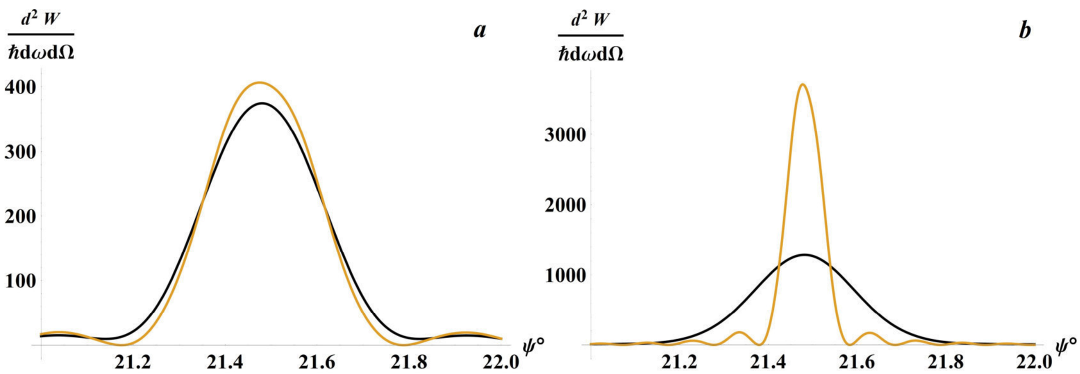

Fig. 3. The angular distribution taking (black line) and not taking (orange line) into account multiple scattering in a quartz target with a thickness of 200 mcm (a) and 600 mcm (b). Simulation options are the same as in Fig. 2

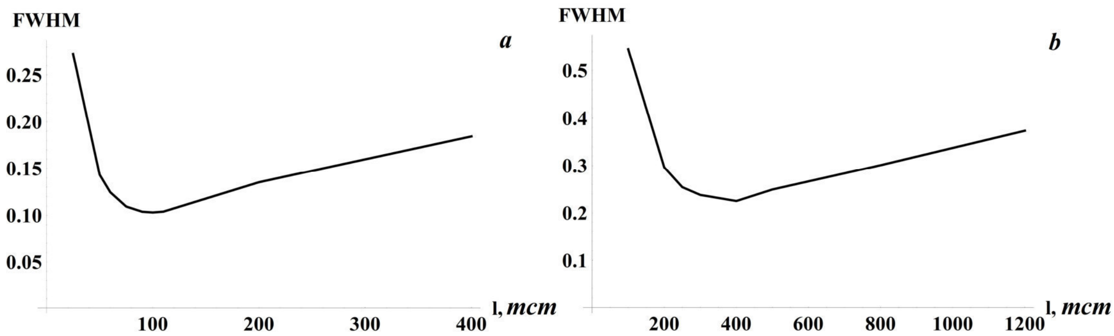

Fig. 4. Variation FWHM from a target thickness for diamond (a) and quartz targets. Simulation options are the same as in Fig. 2

Before that, the distributions with taking into account multiple scattering and without multiple scattering almost coincide. For a diamond target, the angular resolution achieves 0.1 degrees with the thickness of radiator ~100 mcm.

Conclusion. As a result of the investigations, the broadening of the ChR cone was evaluated during the passage of the electrons with energy 6 MeV through diamond and quartz targets. The minimal broadening is observed in ~ 100-mcm thickness diamond and in quartz with 400 mcm thickness.

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