MEASUREMENT OF GAMMA BEAMS PROFILE BY CHERENKOV RADIATION IN FIBERS*

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Abstract

Results of γ-beam profile experimental investigations measuring of Cherenkov radiation [1] generated in an optical fiber with 0.6 mm and 5 mm diameter are presented. These experiments were carried out on γ beams of the linac "Philips SL-75" and the betatron, both with 6 MeV energy. In works [2, 3] authors have showed feasibility of Cherenkov radiation applying for high energy beam diagnostics. In our work the Cherenkov radiation yield dependence on the fiber orientation with respect to the beam axis was investigated and showed that the maximal light yield corresponds to the angle between fiber and beam axes closed to the Cherenkov angle [1]. Proposed technique for measurements of γ and electron [4] beam profiles is insensitive to low energy part of the bremsstrahlung spectrum and to undesirable background in contrast with well-known technique based on ionization chambers. Using such a technique it is possible to construct compact and noise insensitive device. It is also possible to reach submillimeter spatial resolution.

INTRODUCTION

A wide application of γ beams in different fields requires beam profile measurement with a good accuracy. The most wide-spread technique of beam profile measuring is based on its detection by ionization chamber or by scintillator. But these techniques have spatial resolution exceeding 1 mm. One can also use X-ray films [5] to reach submillimeter resolution, but such a technique is an off-line one. All these disadvantages indicate a necessity of new, alternative device development.

In works [1–3] a feasibility of Cherenkov radiation applications for high-energy beams diagnostics is shown. In this work a diagnostic technique for γ-beams with MeV energies and mm sizes is suggested. This technique is based on detection of Cherenkov radiation, generated by γ or electron beams, passing through the optical fiber.

Cherenkov radiation is emitted in cone with the opening angle [1]:

$$\cos\theta_{ch}(\lambda) = \frac{1}{\beta n(\lambda)} \qquad (1)$$

where $\beta = v/c$, λ - wavelength, n - refractive index.

Number of photons, emitted by an electron, can be estimated from [1]:

$$\frac{d^2N}{dx d\lambda} = 2\pi\alpha\left(1 - \frac{1}{\beta^2 n^2}\right)\frac{1}{\lambda^2} \qquad (2)$$

where x - passed by a particle distance, α - thin structure constant, z - particle charge. The estimation of Cherenkov photons yield in glass for the λ = 400÷700 nm gives result about 20 photons per 1 mm. The outgoing angle for photons in glass (n = 1.47) is $\theta_{ch} \approx 46^o$.

MEASUREMENTS OF THE LINAC GAMMA BEAM

Experimental setup

A schematic of experimental setup is shown in Fig. 1. The γ-beam generated by the linear accelerator "Philips SL-75" was registered by the optical fiber with 0.6 mm diameter, which was connected to the silicon photomultiplier (PMT). The fiber length was about few meters, this allowed the locate PMT far from the beam. The accelerator has 6 MeV energy, 1 GHz frequency and 4 μs duration. The dose rate at 0.5 m distance from collimator was 4 Gr/min. The fiber was located at 20 cm distance from the collimator. An orientation dependence of intensity on angle θ between a beam axis and fiber was measured for angular range $0^o \div 180^o$.

The PMT has 6×6 mm^2 active area, 300÷800 nm spectral range, 47% photon registration efficiency at 420 nm wavelength, 10^6 gain coefficient and low supply voltage - 24.5 V. Additional advantages of the PMT are its compact size, insensibility to influence of magnetic fields, mechanical reliability, weak reaction on ionization radiation and possibility of operation in vacuum.

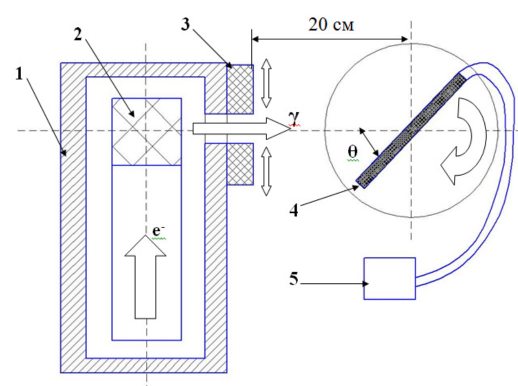

Figure 1: Schematic of experimental setup. 1 - radiation shielding, 2 - linear accelerator, 3 - collimator, 4 - optical fiber, 5 - silicon PMT.

Results

In Fig. 2 the orientation curves for different collimator sizes are shown. These curves were measured by the fiber

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for changing collimator sizes from 35 mm up to 120 mm. Cherenkov angle for glass ($n = 1.47$) is $\approx 46^o$, the experimental outgoing photon angle is about $46^o \pm 3^o$ in good agreement with estimations.

The decreasing of collimator slit size gives distortion of characteristic picture of Cherenkov radiation. When a collimator slit size is less than $\approx$10 mm the surface of the fiber rotated at angle more than $\approx 10^o$ does not give significant contribution in the measurement and the maximal photon yield corresponds to the zero angle, therefore there is no need to use the fiber rotated at 45^o for scanning of γ beam with sizes less than 40 mm.

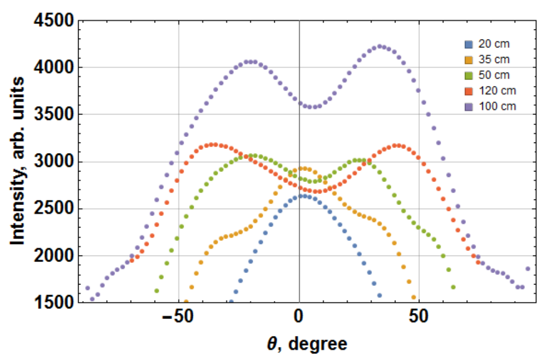

Figure 2: Orientation dependencies for different sizes of collimator.

A vertical profile of the beam at 350 mm distance from the collimator, measured by the fiber, is shown in Fig. 3. The collimator size was 4 cm. This profile was compared with the same one measured by UNIDOS detector [6], which is shown in Fig. 4. One can see that results of both measurements agree good. The technique based on fibers provides spatial resolution $\approx$0.6 mm, whereas the UNIDOS detector resolution is in the range of a few mm.

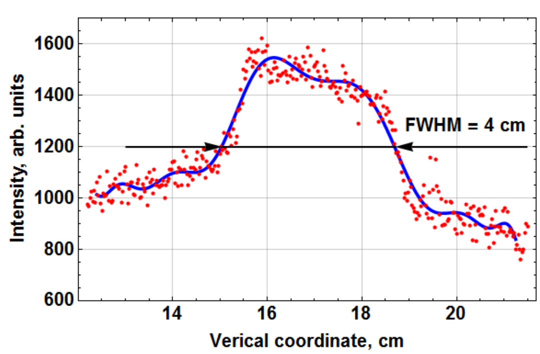

Figure 3: Vertical profile of the γ beam, measured by the fiber. Points - experiment, curve - smoothed dependence.

MEASUREMENTS OF THE BETATRON GAMMA BEAM

Experimental setup

The schematic of the experiments is shown in Fig. 5. In this case we used a glass rod with 5 mm diameter and 200

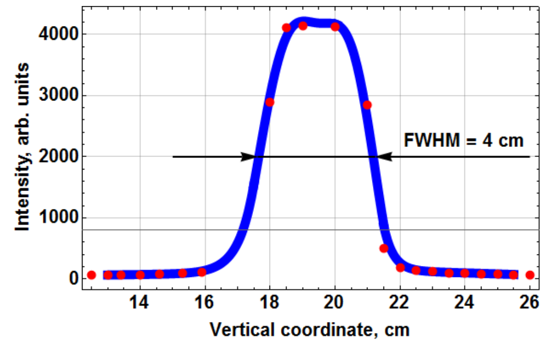

Figure 4: Vertical profile of the γ beam, measured by the UNIDOS detector. Points - experiment, curve - smoothed dependence.

mm length instead the fiber, because the betatron dose rate (1.2 mGr/min at 1 m distance from the injector) is too weak for registration by the 0.6 mm glass fiber. The rod was always inclined relatively to the beam axis, otherwise the PMT could be on the beam way. Inclination angle was $\approx 30^o$. The energy of electrons was 6 MeV.

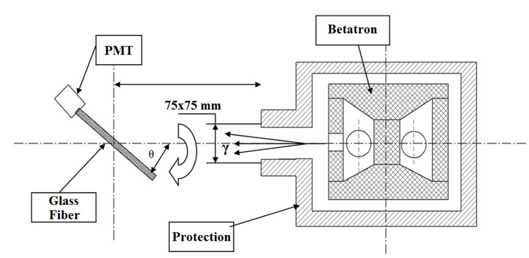

Figure 5: The schematic of betatron experiments.

Results

In Fig. 6 one can see the orientation curve measured with the glass rod. The collimator size was 75 mm. There is no Cherenkov radiation observed within small dose rates (about mGr/min) at the rotation angles close to $\theta = 0$.

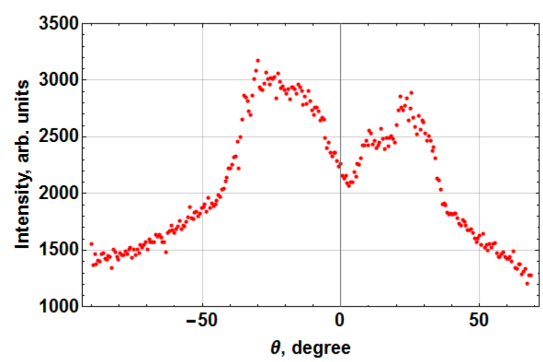

Figure 6: The orientation dependence for the betatron γ beam.

Fig. 7 demonstrates horizontal profile measured with the rod after 10 mm collimator at 125 mm distance. The size was determined only by the "plate" part, as one can see, because

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of the 5 mm diameter of the rod: when the rod is completely irradiated by the γ beam it gives constant intensity, but when it begins to go out of the field the intensity decreases, therefore we have to take into account only "plate" part. And of course the rod inclination distorts the measurement.

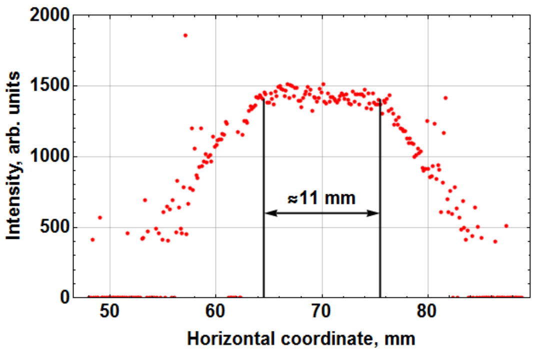

Figure 7: The γ beam profile after 10 mm collimator at 120 mm distance.

CONCLUSION

- A dose rate less than 10 mGr/min doesn't allow to measure Cherenkov radiation using 0.6 mm glass fiber;
- Measurements of the γ beam profile with size less than 1 cm can be carried out, when the fiber is located parallel to the beam axis;
- Measurements with 0.6 mm fiber, rotated at small angles relatively to the beam axis, give maximal yield of Cherenkov radiation within dose rates larger than Gr/min.
- During several days of measurements on the linac there were not found any changes of optical properties of the fiber.

The experimental results demonstrate a feasibility of transverse γ beam profile measurements with mm sizes and MeV energy with a help of optical fibers. Proposed technique has simple realization, small sizes, and high signal/noise ratio. The main advantage of the proposed technique is parallel location of the fiber relatively to the beam direction.

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