Microbeam divergence from glass capillaries compared with simulation for biological use

T. Ikeda,[*1] R. J. Bereczky,[*1] T. Kobayashi,[*1] Y. Sakai,[*2] and T. Abe[*1]

Heavy-ion beam irradiation at relatively low doses induces mutations at a high rate without severely inhibiting growth. As DNA, which is relevant to mutation, is localized in a cell, micrometer-sized beams should be used to irradiate the DNA effectively. When a megaelectronvolt-energy ion beam is transmitted through a tapered glass capillary with a micrometer-sized outlet, the extracted beam can be utilized as an ion microbeam for cell irradiation [1)]. The capillary is closed by a thin end-window at the outlet to maintain the inner vacuum so that the outlet can be close to the target cells in water solution. In the case of thinner capillaries (order of 1 μm), the divergence of the transmitted beam has been investigated. However, larger outlets (10 μm or more) with end-windows need further study because the probability of mishitting the neighboring cells due to larger lateral momentum components of ions should be determined before experiments.

In our experiment, He^{2+} ions with an energy of 4.5 MeV from the Pelletron accelerator at RIKEN were used and transmitted through capillaries with different outlet diameters of the order of 10 μm, where the inlet diameter and the length were 800 μm and ~5 cm, respectively. The beam profile was obtained with pieces of a plastic tracking detector, CR-39, in air 6 mm downstream of the capillary and then compared with simulated data using SRIM (TRIM) code. The distance between the capillary outlet and the target was determined so that the ion hit points are sufficiently separated from each other to be observed by a microscope with good statistics. The beam divergence inside the capillary is parameterized in the simulation, where ions start at the upstream side surface of the end-window with a homogeneous distribution for initial positions and with a distribution of lateral momentum components expressed by a single parameter, σ_θ, the standard deviation of a Gaussian distribution. Most of the experimental hit point distributions on the CR-39 pieces are well reproduced even when single σ_θ was selected properly. In this case, a difference in σ_θ of 0.1° reflects a large change in chi-square for the comparison [2)]. However, some of the capillaries showed more out-going events. This fact implies the divergence inside the capillary may have multi-parameter σ_θ's. This idea has been reported by Hasegawa et al. [3)], who introduced a 'core' component as well as a 'halo' component. Figure 1 shows the hit point distributions of the experimental and simulated results as a function of the distance between a hit point and the beam axis (or the weighted center for experiments), *r* in micrometers. As a trial, σ_θ of 1.35° for Fig.1(a) and σ_θ of 3.00° for (b) were selected after a rough scan in σ_θ. Both plots do not show an agreement between the experimental and simulated data. Figure 1(c) shows that simulated data of linear combination (a) ×1 + (b) ×0.32 reproduce the experimental spectrum, where the coefficient of the combination was obtained by chi-square fitting. It shows that more than one component of the beam spread during the transmission is needed. In order to reduce the halo component, how and what amount of such events is generated and what shape of the capillary is best should be investigated. We have started a realistic GEANT4 simulation that allows us to install the complicated capillary shape [4)]. Figure 1(d) shows a typical event display with a capillary outlet size of 20 μmϕ and end-window of 3 μm[T]. After the installation of the measured capillary, a simulation with not only parallel incoming beams but also spread/focused beams adjusted by a Q-magnet upstream of the capillary is scheduled.

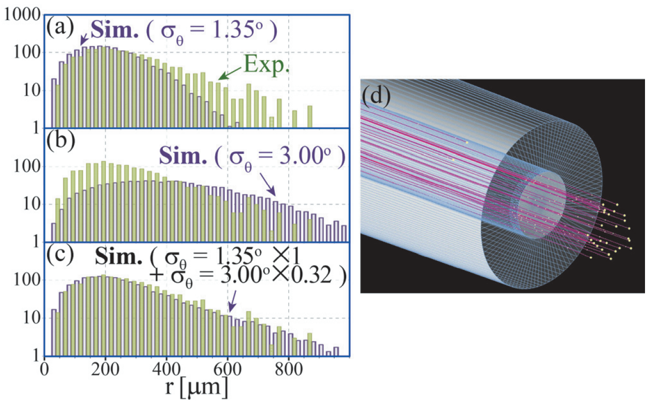

Fig. 1. Comparison between experimental (green) and simulated (purple) spectra. The experimental spectra are the same through (a)-(c). The heights of the spectra for the simulated results in (a) and (c) are normalized so that the peak heights are similar to those of the experimental results. The normalization factor for (b) is the same as that for (a). (d) A typical event display of GEANT4 for the trajectories of He^{2+} with 4.5 MeV stopping (at yellow points) in water solution.

References

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*1 RIKEN Nishina Center
*2 Department of Physics, Toho University