5 - 39 Design of 50 MeV Proton Microbeam Based on Cyclotron Accelerator

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A 50 MeV proton microbeam facility that can provide accurate irradiation dose delivery is a powerful tool in space science, biology and cancer therapy studies. However, the poor beam quality of the cyclotron and the intense scattering at the slit position are the main challenges of the 50 MeV proton microbeam system. We present the optical design for a cyclotron-based 50 MeV proton microbeam system with a micro-sized resolution. Figure 1 shows the scheme of the 50 MeV proton microbeam system. Due to the large emittance and momentum spread of the beam provided by the cyclotron, as well as the mass of scattered protons generated by the interaction of 50 MeV protons with the slit material, the Oxford triplet lens configuration with small aberrations and a high atomic number tungsten carbide slit were chosen for the 50 MeV microbeam system[1]. The beam optical parameters for the 50 MeV microbeam system with Oxford triplet lens configuration are shown in Table 1.

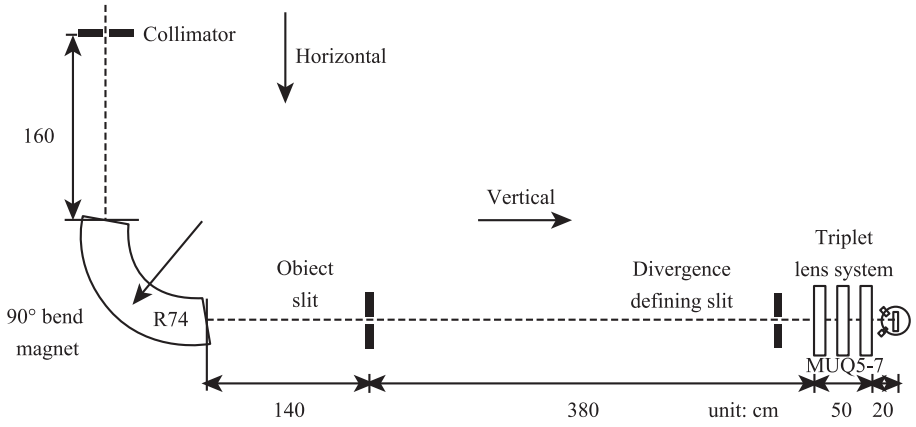

Fig. 1 (color online) Scheme of the 50 MeV proton microbeam system.

According to the calculations in Table 1, spherical aberrations can be ignored, while chromatic aberrations are the main factors affecting the micro-beam resolution. In this microbeam system, a 90-degree bending magnet with the slit system can be used to filter particles' momentum spread and reduce chromatic aberrations. Figure 2(a) shows the distribution of 10 000 protons in the image plane. That these protons are evenly distributed without significant distortion, thanks to the small aberrations of this system, with the slit parameters and momentum spread in Table 1. In addition, a slit system model was established to study the effect of the proton scattering, using the Geant4 toolkit as shown in Fig. 2(b). The distance between the object slit and the divergence defining slit is 3.3 m and data collection surface with 3 mm×3 mm square is placed behind the second divergence defining slit to collect the information of particles that can pass through the slit system. Then the incident beam of 10^6 protons with a diameter of 1 mm and a divergence angle of 1 mrad in both directions was shoot into the slit system. As shown in Fig. 2(c), with the slit setting for the 10-μm microbeam spot given in Table 1, the proportion of scattered protons reaches 12.3%. The result shows that the effect of scattered protons is less significant for the slit setting for the 10-μm microbeam spot. Then the energy information of passed protons was analyzed, as shown in Fig. 2(d). The energy of most scattered protons is much lower than 50 MeV. This indicates that most scattering protons undergo multiple scattering in the slit system. Therefore, most of them will have a large divergence angle and be blocked by the subsequent beamline tube. So, a 50 MeV proton microbeam system based on a cyclotron with a micron-sized beam spot is feasible.

Table 1 Beam optical parameters for the triplet lens configuration were calculated by WinTrax.

Factor	Oxford triplet
Demagnification factor	
D_x	−11.12
D_y	36.15
Chromatic aberration coefficients (μm/mrad%)	
$<x/\theta\delta>$	460.87
$<y/\phi\delta>$	−184.77
Spherical aberration coefficients $(\mu m/mrad^3)$	
$<x/\theta^3>$	−28.74
$<x/\theta\phi^2>$	−25.5
$<y/\phi^3>$	10.56
$<y/\theta^2\phi>$	7.87
$\alpha/\left(rad^2/m^2\right)$	0.47
$Q/\left(mrad^2/\mu m^{2/3}\right)$	64
Excitation of the 1st and 2nd lens/T	0.627
Excitation of the 3rd lens/T	0.747
Slit parameterswith 10 μm final beam diameter $(\mu m^2 mrad^2)$	$110\times0.2\times360\times0.4=3168$
Slit parameterswith 1 μm final beam diameter $(\mu m^2 mrad^2)$	$10\times0.04\times36\times0.04=0.576$
Momentum spread /%	0.02

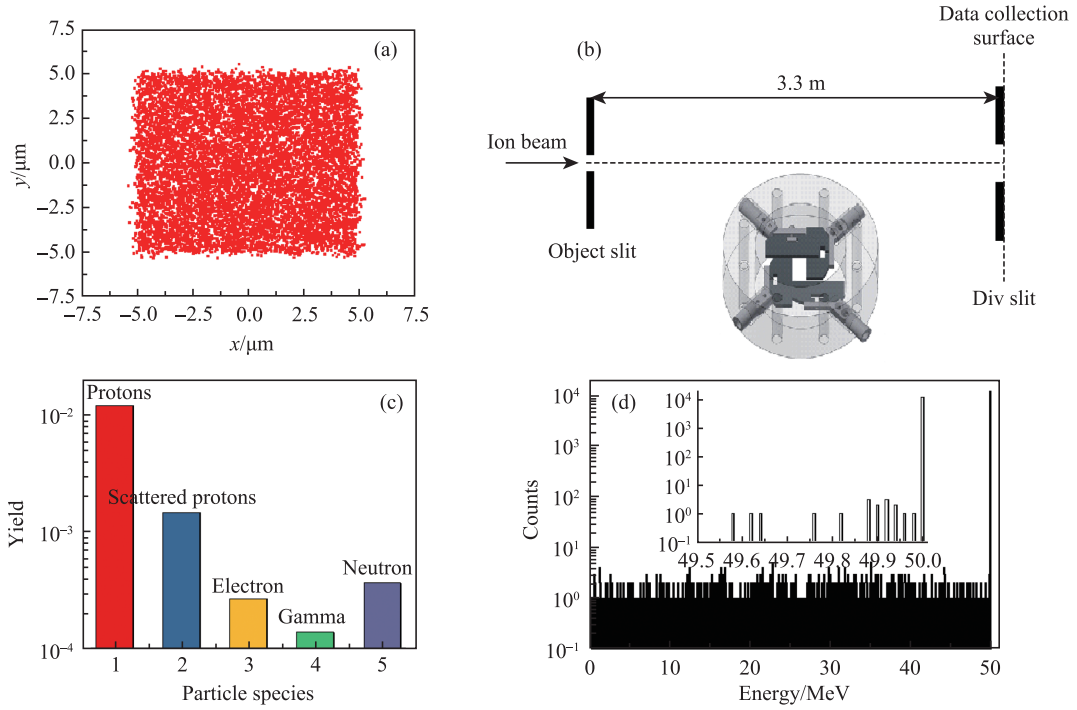

Fig. 2 (color online) (a) Spatial distribution of protons at the focused image plane raytraced with 10 000 protons for 10 μm beam spot, parameters are given in Table1, (b) The slit model in the microbeam system, the slit system model is composed of a piece of solid cubic (WC+8%Co) of 3 mm thick, (c) Detected particles with two slit system settings of 110×0.2×360×0.4 $\mu m^2 mrad^2$, (d) Energy spectrum of the transmitted protons with slit setting of 110×0.2×360×0.4 $\mu m^2 mrad^2$, incident proton energy is 50 MeV.

Reference

[1] F. Watt, NucL. Instrum. Meth., 197(1982)65.