Consideration of using non-destructive detectors in the beamline of a proton therapy facility

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Abstract:
Ionization profile monitors (IPM) are a kind of nondestructive monitors mostly used in accelerators of high intensity pulsed beams. As for particle therapy accelerators, either based on cyclotrons or synchrotrons, the extracted beams are very weak, usually on the level of nano-Amperes. Up to date, the commonly used detectors in such low current machines are all destructive, such as fluorescent screens and gas ionization chambers. In this paper, we proposed for the first time to use a residual gas ionization monitor to measure the beam profiles in a proton therapy facility based on a superconducting cyclotron. The feasibility of such a scheme and some basic issues are discussed in this paper.

There is a proton therapy facility based on a superconducting cyclotron under construction in the Huazhong University of Science and Technology (HUST-PTF). The layout is shown in Fig. 1 and the beam parameters from the superconducting cyclotron are summarized in Table 1.

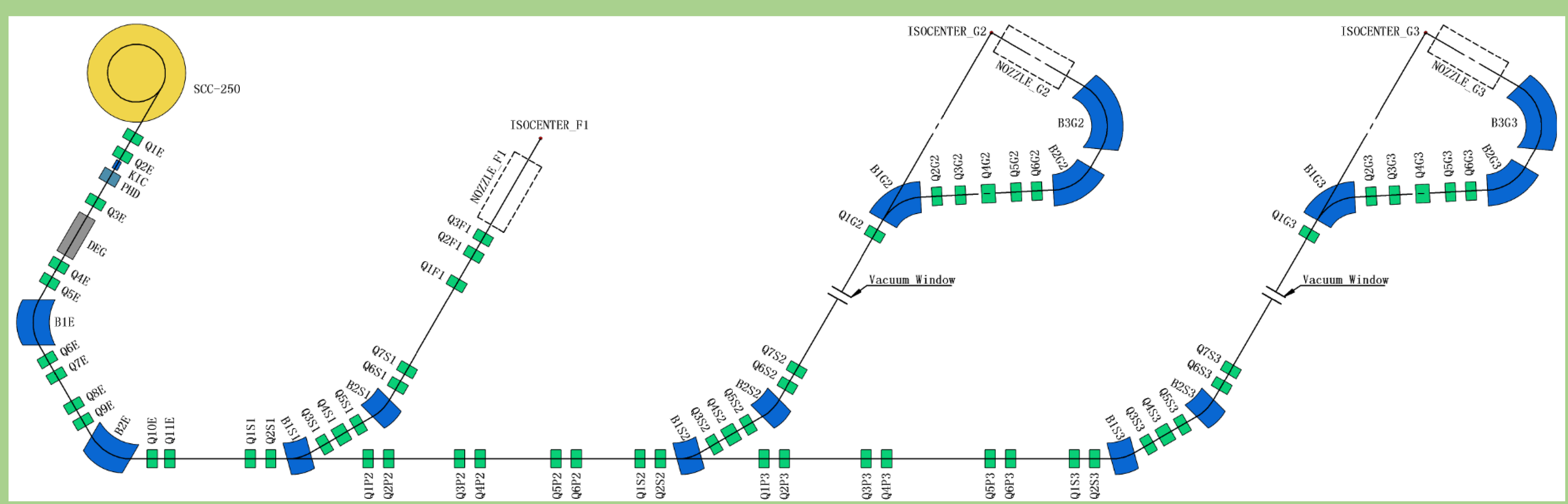

Fig. 1: Lattice of the HUST-PTF.

Frequency	73MHz, CW mode
Energy	250 MeV
Energy spread	< 0.5%
Intensity	60 ~ 500 nA

Table 1: Beam parameters from the CYC.

The proton beam extracted from the cyclotron has a fixed energy of 250 MeV and then is modulated to 70 ~ 230 MeV with an energy degrader. It is demanded that the cyclotron has the ability to output different intensity beams in accordance with the working energy points. The beam intensity from the cyclotron is divided into three levels (Fig. 2) and the final intensity for clinical treatment is shown in Fig. 3.

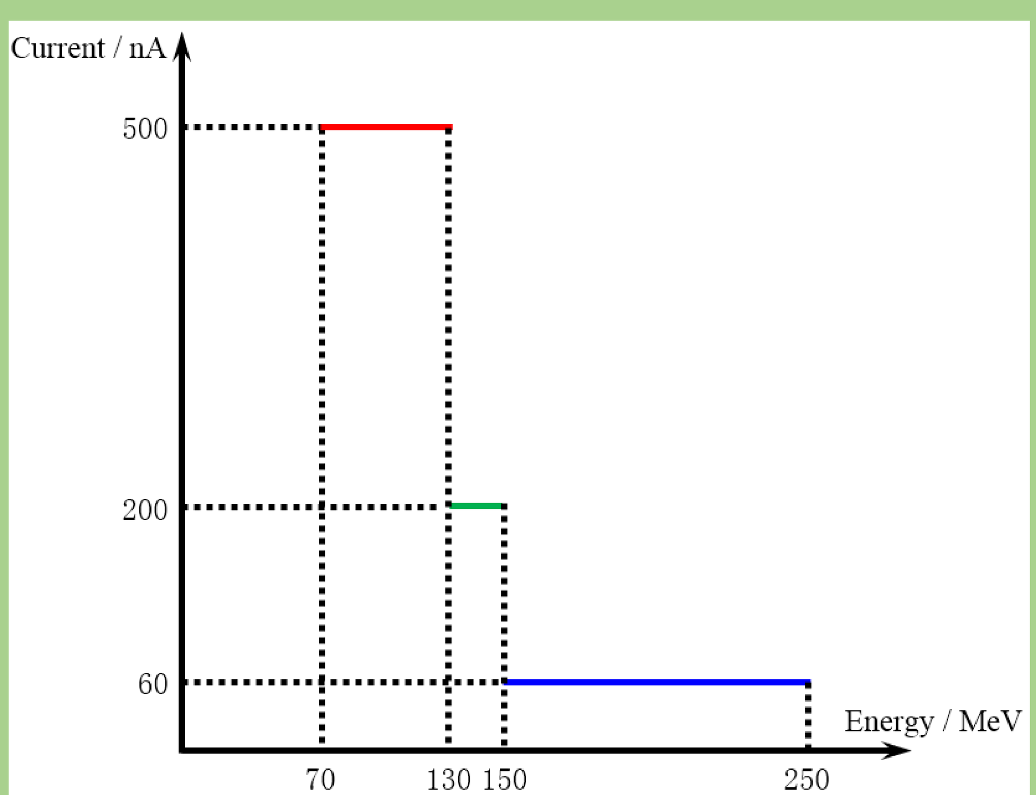

Fig. 2: Different extraction current from the CYC.

The gain is calculated from the energy of proton beams deposited in the residual gas and the ionization energy of the gas. The parameters used in our simulation is displayed in Table 2.

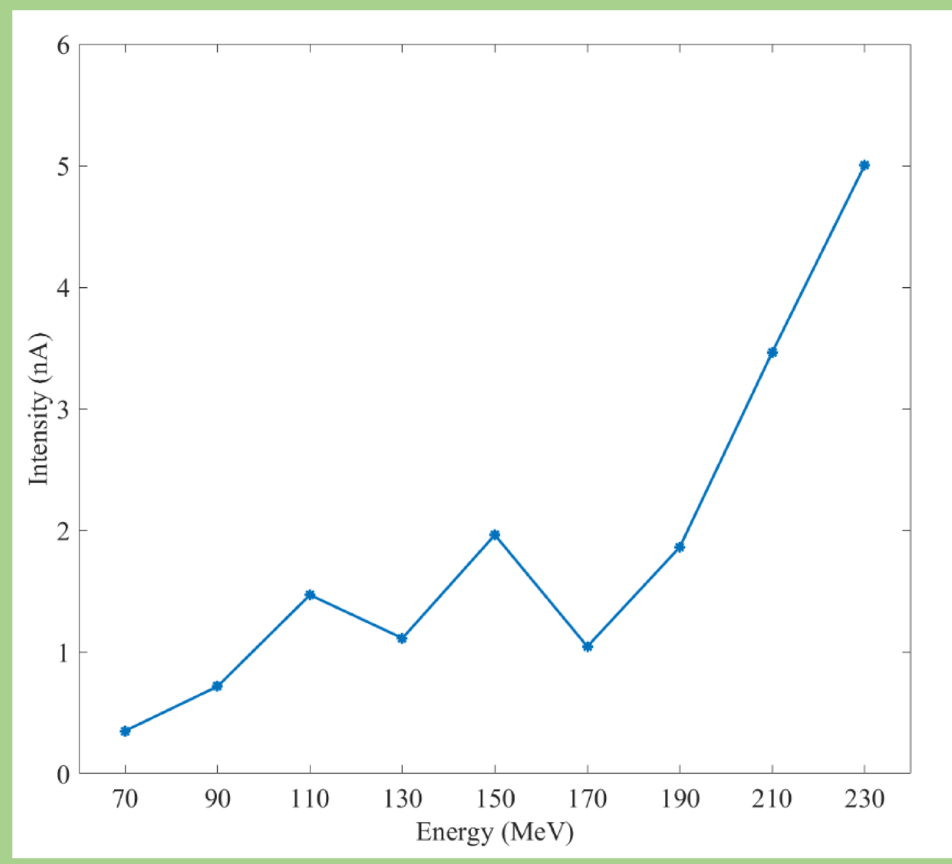

Fig. 3: Working points of the transport line after the energy selection system.

$$-\frac{dE}{dx} = \left(4\pi N_a r_e^2 m_e c^2\right)\left(\rho\frac{Z}{A}\right)\left(\frac{z^2}{\beta^2}\right)\left[\ln\left(\frac{2m_e c^2\beta^2\gamma^2}{I}\right)-\beta^2\right]$$

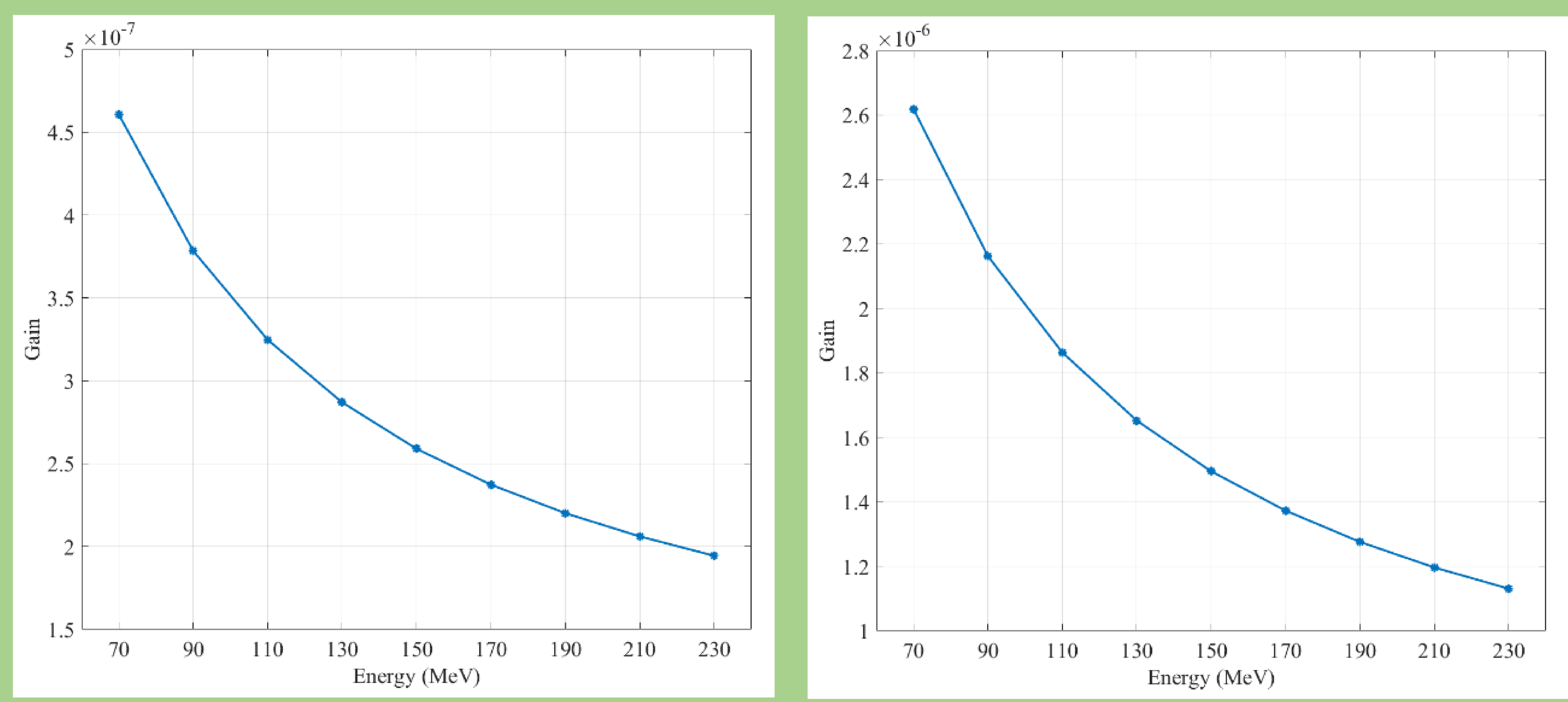

Fig. 4: Gain curves of the H_2 (L) and the N_2 (R) at 10^{-4} Pa.

Table 2: Simulation parameters for the gain of H_2 and N_2

Pressure	10E-4 Pa
Temperature	298.15 K
Detector length	10 cm
Ionization energy	36 eV of H2, 36.4 eV of N2

Fig. 3 indicates the beam intensity increases with the beam energy while Fig. 4 indicates the gain decreases with the beam energy. Combining the results in Fig.3 and Fig. 4, the lowest ionization signal occurs at the 70 MeV point, which corresponds to 1009 ion-electron pairs per second. It should be emphasized that the time resolution is not an important issue in the beam diagnostics of our machine and only the average parameters are concerned. With the help of a typical two-stage MCP with a gain of 10^6 ~ 10^7, we feel confident in applying such an IPM detector in our machine.

Although the simulation results suggest an acceptable signal level from the IPM, it is still worth noticing that the ionization pair is relatively low, which indicates the signal would be easily influenced by the background noise and statistical errors.

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