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NIMA POST-PROCESS BANNER TO BE REMOVED AFTER FINAL ACCEPTANCE

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Abstract

Beam profiling during patient treatment in protontherapy requires ultra-thin monitors to preserve the high beam quality. For detectors upstream in the line, a material budget as low as $\sim$ 15 μm water-equivalent is needed. In addition, the current trend of dose escalation to treat highly resistant tumors implies challenging requirements on monitor radiation hardness and dynamic range. We propose a new type of beam profiler, PEPITES, using secondary electron emission (SEE) and built with thin-film techniques. The beam is profiled by crossing a pattern or a series of patterns which emit the SEE signal and can be made ultra-thin as SEE originates from the few nanometers next to the surface. The patterns are deposited on membranes, which, in contrast with common systems like ionization chambers, are free from mechanical constraints and can then afford higher absorbed doses and be as thin as achievable. A simple demonstrator prototype has been built and successfully operated with a proton beam at the ARRONAX cyclotron at St Herblain in a wide range of currents (100 fA to 10 nA) and several energies (30 - 68 MeV). Beam profiling results from these tests are presented, and our plans for the next prototypes are mentioned.

Keywords: , beam profiler, thin film, protontherapy

1. Motivation and detector principle

Protontherapy exploits the property of protons to deliver the maximum dose at the end of their track, resulting in the highest level of damages in the stopping area, deep in the tissues, called the Bragg peak. The depth can be adjusted by adapting the beam energy (between 70 and 230 MeV for medical cyclotrons). It is a benefit compared to gamma beams which deliver dose all along their paths. Moreover, with low lateral scattering in the tissues, proton beams remain focused on the tumor. The main medical indications are resistant, inoperable or pediatric cancers. Dose delivery requires a continuous and precise measurement of beam intensity, position and profile. When crossing the monitor material thicknesses, the beam undergoes a dispersion that should lead to a maximum sub-millimeter lateral spreading at the patient to be tolerable. The continuous presence of the monitor in the line also requires good resistance to radiation. The current trend of dose escalation to treat very resistant tumors with high intensity beams increases the demand on monitors radiation tolerance and on their dynamic range.

We propose a 10 μm Water Equivalent Thickness beam monitor with high durability, wide dynamic range and easy operation. The device uses secondary electron emission (SEE) phenomenon. As a surface process, SEE allows very thin active layers: 5 nm of matter are sufficient to generate the full signal. Secondary electrons have very low energies (few eV) which implies to work in vacuum, in compliance with our use-case. The SEE yield is proportional to the dE/dx of the beam particles ([1], [2]) and is independent of the beam intensity up to currents far beyond the medical needs. The device contains one or several segmented electrodes which emit the signal when crossed by the beam. Their pattern is adapted to the beam to be profiled and is composed of conductive elements read independently. Patterns are deposited by metal evaporation or by sputtering onto thin non-conductive substrate and can be strips, pads, etc. Their thickness has to be large enough to allow electrical conduction, which requires ∼ 30 nm for a metal. The baseline monitor consists in two strip-based electrodes to measure the beam along the X and Y axes, perpendicular to its direction, and collection electrodes. Gold strips onto organic thermostable polymers have been used so far.

2. Experimental setup

We built a prototype profiler consisting of two electrodes (emission and collection) separated by a 1 cm gap. The emission electrode allows to test two different material combinations. The first one consists of gold strips (50 nm thick, 1.6 mm width, 0.35 mm interstrip, 6 cm length) on a 6 µm PEEK foil substrate. The second part is a 100 nm thick, 1.4 x 1.4 cm^2, Si_3N_4 membrane with one large gold strip (50 nm thick). The collection electrode is a 100 nm gold layer onto a 8 µm, 6x6 cm^2, Kapton® foil. Gold metallization was made by chemical vapor deposition on the polymers and sputtering on the Si_3N_4 membrane. A +100V potential is applied to the collection electrode. A single low noise pico-ammeter (Keithley 6517B) is used for the signal readout. It is connected to the strips through a switch matrix to sequentially select the read strips. Command control and data acquisition are handled by the Pyrame framework developed at the LLR [3]. The detector is installed in a 25 cm diameter cylindrical vacuum chamber placed on a translation table for alignment with respect to the beam line exit about 1 meter away. The chamber is equipped with 60 mm diameter entrance/exit beam windows made of a 3 mm sapphire glass in a first run (2016/09) and 230 µm Kapton® foils in a second run (2017/03), to decrease the beam dispersion and the activation of the system. SRIM [4] has been used to calculate the beam energy loss from the beam line exit to the detector.

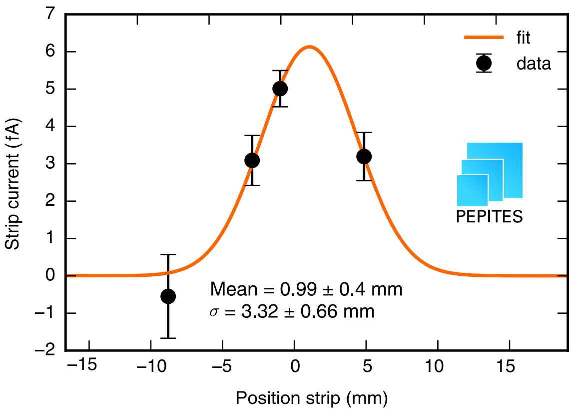

Figure 1: Profile with protons 60 MeV, I_{beam} = 170 fA, 4 strips connected

3. Results and discussion

Measurements have been carried out at the ARRONAX cyclotron at St Herblain[5]. Profiles have been determined for

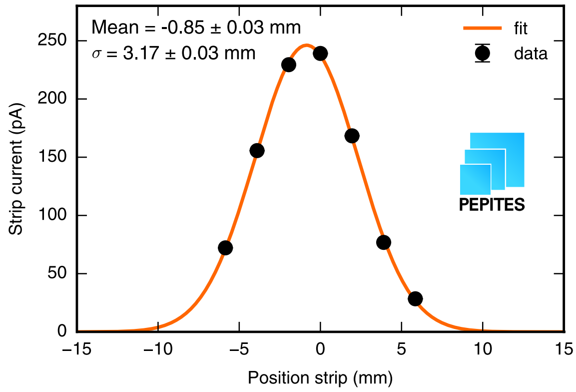

Figure 2: Profile with protons 66 MeV, I_{beam} = 10 nA, 7 strips connected

a wide range of protons beam currents: 170 fA up to 10 nA (Fig 1 and 2) and for several beam energies: 66, 60 and 27.9 MeV. In addition, the beam profile at I_{beam} = 100 pA has been compared to the one measured by the DOSION[6] monitor, and found compatible. Signal with Si_3N_4+ gold sample has also been observed for different beam currents.

4. Conclusion

The principle of an ultra-thin beam monitor using SEE and based on thin film techniques has been validated. The next steps include studies on radiation tolerance, alternative patterns and materials, the development of a low noise electronic ASIC, to finally achieve a fully functional prototype of at least 2x8 channels.

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