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Ion imaging and material determination using a beam telescope

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Ion-beam therapy has become a well-established method to treat deep-seated malignant tumors. Typically, the treatment planning is based on an x-ray computed tomography (CT) scan, which is performed prior to irradiation. However, in the planning process, the Hounsfield units (HU) that are obtained from the x-ray CT scan have to be converted to relative stopping powers (RSPs), which describe the energy loss of an ion beam within the investigated tissue. To avoid this conversion and the accompanying uncertainties in the dose distribution, the idea of ion imaging, which directly returns RSP values, was developed.

A typical ion CT system consists of an upstream and a downstream tracker (to measure each ion's position and direction) and a range or energy measurement device (range telescope or calorimeter). A small ion CT demonstrator system was developed by HEPHY and TU Wien and tested at MedAustron, an ion therapy center in Wiener Neustadt, Austria. The system consists of four double-sided silicon strip (DSSD) detectors with an active area of 2.56 x 5.12cm^2 and a range telescope composed of plastic scintillator slabs. Besides conventional ion CT, recent measurements with the demonstrator included scattering radiographies and attenuation radiographies with high statistics (O(10^6-10^7) protons per image).

For a full ion CT scan, the setup has to be rotated around the patient or object to be imaged (phantom) and measurements are taken at several angles. In order to obtain a 3D map containing the RSPs, a reconstruction algorithm, which takes the non-straight ion paths into account, is essential. Recent developments within the CT reconstruction toolbox TIGRE for ion CT image reconstruction will be presented. Furthermore, hardware and software investigations for a future upgrade of the ion CT demonstrator will be discussed. On the hardware side, this includes the newest research results for an ion CT system based on 4D-tracking detectors and a residual energy measurement based on time-of-flight. Such a system was studied using Monte Carlo simulations and was shown to yield RSP errors < 0.6 %.

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