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THE BERGEN PROTON CT PROJECT –PROTON TRACKING IN A HIGH- GRANULARITY DIGITAL TRACKING CALORIMETER

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Introduction: Particle therapy, a non-invasive technique for treating cancer using protons and light ions, has become more and more common, e.g. Norway has decided to build two particle treatment facilities, one of which will be located in Bergen. Being able to position the Bragg peak accurately is a major advantage of protons and light ions, but incomplete knowledge about the tissue properties and their relative position limits the precision. Range uncertainties of several millimetres may arise, mainly due to the — not one-to-one — conversion of photon attenuation maps from computed tomography (CT) scans into relative stopping power. A proton/alpha CT scanner provides direct information about the stopping power and has the potential to reduce range uncertainties from current values of 3-10 mm to about 1 mm.

Proton CT: For a proton CT scan the particles — typically protons or alpha particles — need to be energetic enough to traverse the patient completely, so that the Bragg peak is positioned in a calorimeter. The trajectories of every outgoing proton, as well as the residual energy/range, is measured. The calculation of the proton trajectory inside the target region and the measured residual proton energy/range provide a 3D-map of the relative stopping power. During a scan, the patient needs to be rotated to obtain projection data from a set of different angles. Prototypes of pCTs have been built and tested in beams (see e.g. [1,2]); however, readout rates are currently limited to several MHz. In order to use a pCT in a clinical environment, the total scanning time has to be reduced to the order of minutes or, even better, seconds.

Digital tracking calorimeter: A (pre-)clinical prototype of an extremely high-granularity digitial tracking calorimeter has been designed and is being constructed. The latest developments in Monolithic Active Pixel Sensors (MAPS) technology allow the fabrication of extremely-high granularity, low material budget and large area silicon detectors with integration times of microseconds and sparsification/zero-suppression of the data on the sensor itself (see e.g. [3]). The prototype is a silicon/absorber sandwich calorimeter with 41 sensitive layers of MAPS [4,5]; the absorber material is aluminium. The first two tracking planes (27cm x 18cm) are ultrathin layers of sensors thinned to 50 μm, bonded onto thin flex cables and mounted on a carbon fibre carrier. The sensor layers consist of ALPIDE chips originally developed for the upgrade of the inner tracking system of the ALICE experiment at the LHC.

Clinical requirements
The pCT system is designed to operate under clinical treatment conditions, i.e. pencil beam scanning. This implies (1) that the trajectories of the incoming protons are taken from the beam optics (beam spot position, size and divergence) and only the outgoing protons'trajectories and thus their range are measured on a track-by-track basis with high precision and (2) that the proton tracking calorimeter has to handle high local intensities.

Simulations
A complete CT reconstruction of a simulated anthropomorphic paediatric head phantom shows that the concept of a single-sided detector setup and realistic pencil beam parameters gives a spatial resolution sufficient for proton therapy treatment planning [6].

Beam tests
Modules of ALPIDE sensors mounted on thin flexible PCBs and on aluminium absorber plates have been produced. The sensors are read out by an FPGA-based data acquisition system (Kintex Ultrascale FPGA). Stacks of modules were tested in proton, helium and carbon beams at HIT.

The expected performance based on simulations and first beam test results will be presented, e.g. proton tracking accuracy, dE/dx capability, occupancy and rate capability, radiation hardness and 3D spatial resolution after CT reconstruction.

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