**ABSTRACT SUBMISSION FORM**

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**PRESENTATION TITLE**

Experimental validation of magnetic field deflections of proton beams for online MR-guided PT

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**AUTHOR(S)**

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**ABSTRACT**

**Purpose:**
Online MR-guidance for proton therapy is currently gaining interest as it promises to enable real-time adaptive proton treatments, which could significantly improve treatment outcomes for mobile tumours. To assess the clinical benefit of online MR-guided proton therapy, a platform for comprehensive 4D in-silico treatment planning studies is needed. We are working towards a fast Monte-Carlo (MC) platform, capable of simulating the transport of proton beams within moving geometries and in the presence of magnetic fields. This study presents a first experimental validation of the magnetic fields implementation within the fast MCsquare code [1].

**Materials & Methods:**
The MCsquare software was extended by adding support for the simulation of interactions between protons and an external uniform magnetic field. The magnetic forces were calculated at each step of the integration, by solving the relativistic Lorentz equation corrected for the changing particle energy during penetration. The implementation allows for the simulation of resulting dose distributions depending on beam deflection, dose deformation, as well as the impact of material heterogeneities. To validate this model, magnetic deflection experiments were conducted at the KVI-Center for Advanced Radiation Technology (KVI-CART), passing 150 MeV protons through an electro-magnet with maximum magnetic fluxes from 0.5 to 1 T. The beam was a homogeneous horizontal field of 100x2mm. The trajectory of the protons in air was recorded with a polymeric x-ray film (EBT-2), which was tilted in relation to the beam normal angle in order to record its lateral deflection when passing through the magnetic field. The deflection is upward in the vertical direction.

**Results:**
The trajectory of the proton beam was recorded with and without the magnetic field, resulting in a divergent bifurcated image. The x-ray film was set in the geometric center of the electro-magnet, covering a total range of 175 mm. Lateral shifts between 5 and 15 mm were observed throughout this range for magnetic fields with...
Figure 1. Experimental (top) and simulated (bottom) trajectories of 150 MeV proton beam traversing air. The proton beam was recorded with (curved path) and without (straight path) the application of an 1 T magnetic field. The intensities from 0.5 to 1 T. The trajectory tracks were reproduced by MCsquare simulations, when considering uniform magnetic fields of the nominal maximum intensity. Since the experimental magnetic field extends beyond the recorded region, fringe field effects increase the observed deflection shift. This effect was qualitatively accounted for in the simulations by also extending the magnetic field region before the recorded track range.

**Conclusions:**
Proton beam trajectories were recorded in experiments with high initial energies and strong magnetic fields. The lateral shifts observed reflected the deflections simulated by the Monte Carlo algorithm MCsquare. The implementation of the energy-corrected relativistic Lorentz equation was able to describe the beam path, taking into account the particle energy, magnetic field, and material. In a next step, we will advance the magnetic field implementation towards more realistic fields present for online MR-guided proton therapy.

**References:**