Online Beam Monitor for Proton Therapy Beams

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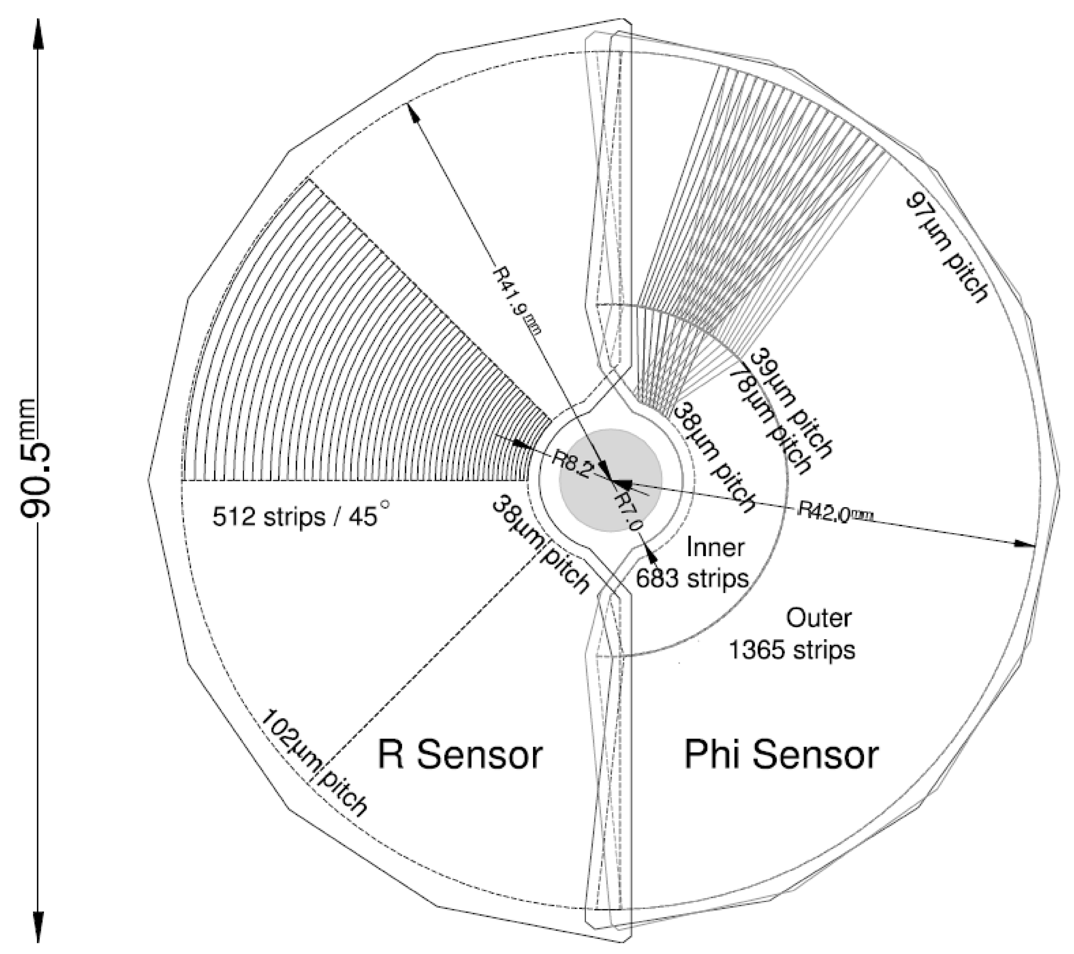
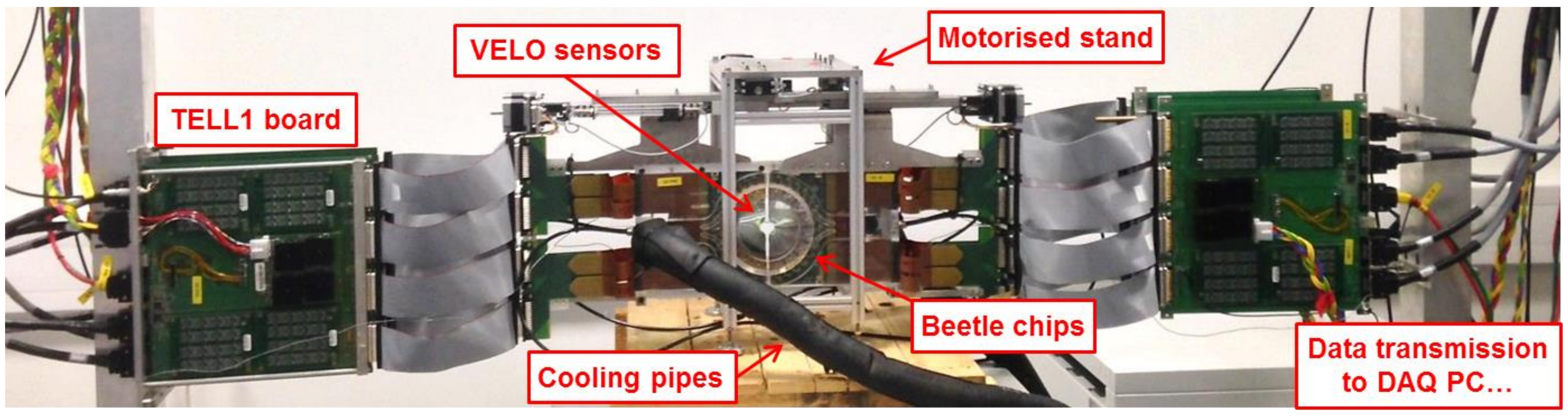
The use of protons to damage cancerous sites offers several advantages over conventional radiotherapy including superior tumour control, sparing of healthy tissue and long term outcomes. In clinical practice, the point of maximal energy transfer - the Bragg Peak, is positioned to precisely deliver a high amount of dose to malignant targets. This requires beam diagnostics in both the accelerator and treatment line to provide accurate measurements to ensure a safe and high quality of treatment. An **online beam monitor based on LHCb VELO technology** is currently under development for proton radiotherapy beamlines. The novel detector design allows **minimal interception of the beam by measurement of the halo and correlation with the beam core**. The system is being firstly optimised for implementation at the Clatterbridge Cancer Centre (CCC) UK, 60MeV proton therapy beamline. This involves **comprehensive beam transport and particle tracking simulations of the CCC beamline to establish a database of halo maps for correlation**. Additional collaborative efforts are also underway to fully characterise the CCC beam and develop a complete verified, standard simulation model for future work at the proton therapy beamline.

VELO Detector



- The LHCb VELO multi-strip, silicon modules track events in a polar coordinate system
- Each semi-circular module half consists of double sided geometry with **R** and **ϕ** sensors
- **8mm aperture** radius allows each module to measure the beam halo without intercepting the core of the beam

		R − sensor		ϕ − sensor	
Silicon technology		$n^+ -$ in $- n$		$n^+ -$ in $- n$	
Number of readout channels		2048		2048	
Thickness of the sensor [μm]		300		300	
Number of sectors (R) / regions (ϕ)		4		2	
Smallest pitch [μm]		38.0		37.7	
Largest pitch [μm]		101.6		97.0	
Radius of active area [mm]	Min.	8.170	Inner	8.1860 – 17.211	
	Max.	42.000	Outer	17.2895 – 41.984	
Angular coverage [degrees]		180		≈ 182	

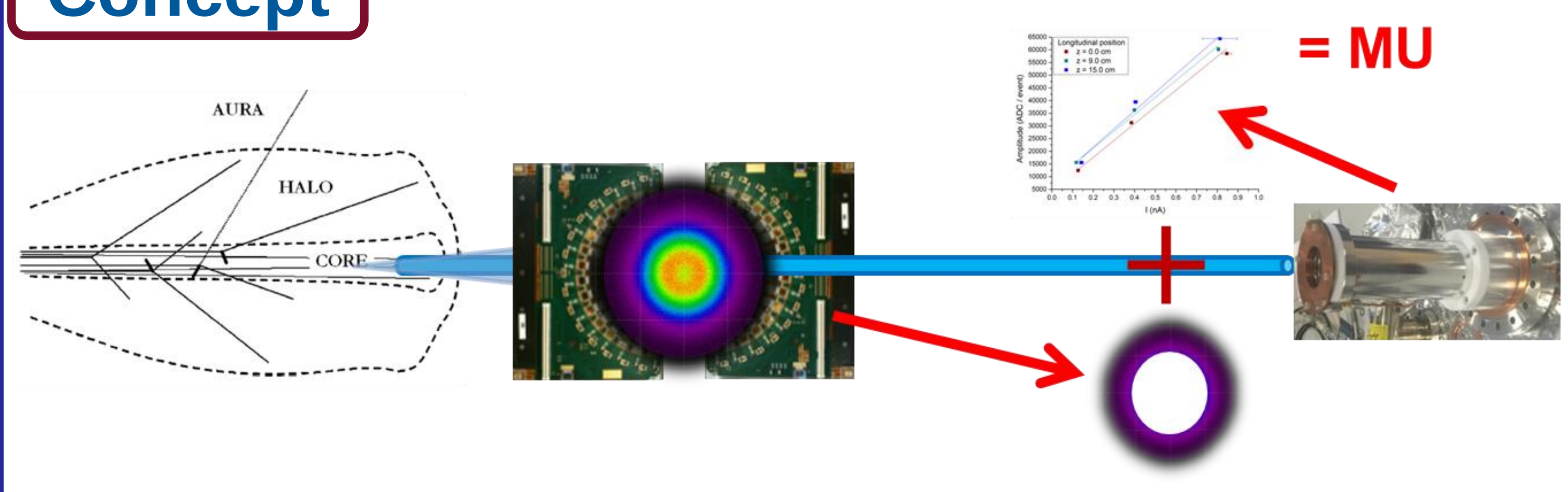


Readout sychronisation & adaptations

Several **hardware and software modifications** were necessary to operate the sensors as a standalone device outside of the LHC environment. These changes include:

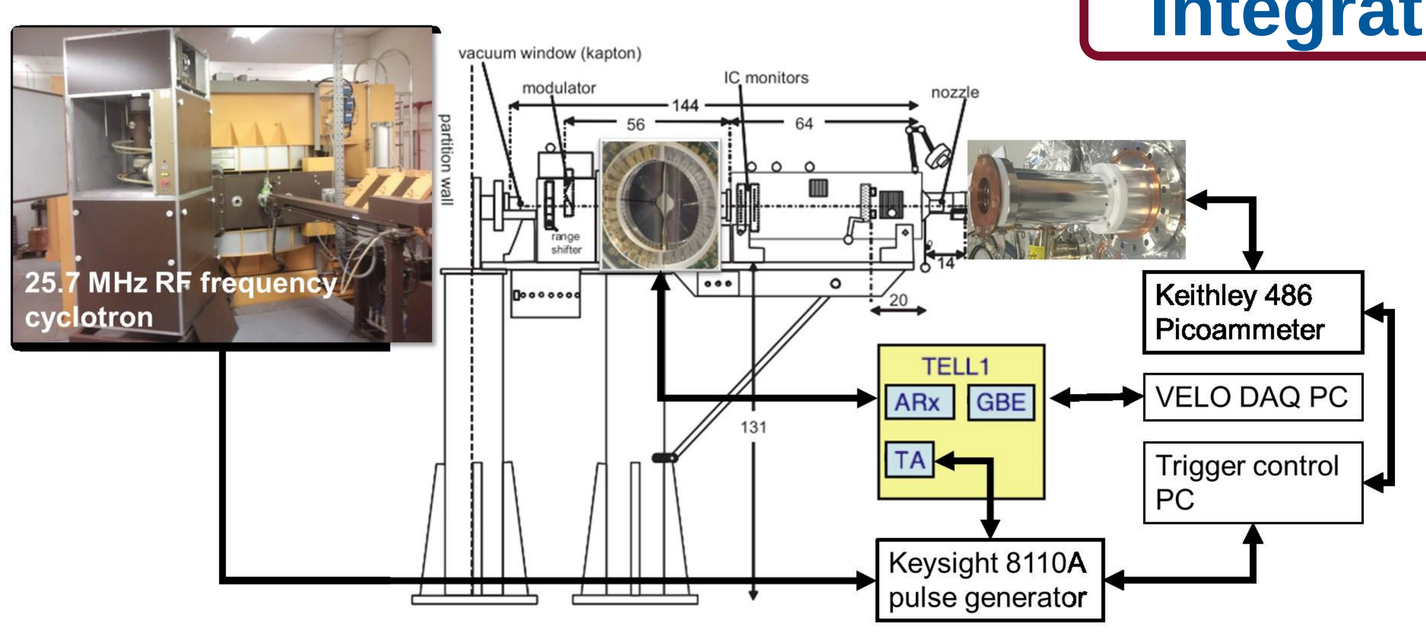
- Air flow and cooling system
  - Operation in air
  - Prevent condensation
- Optimised faraday cup
  - Beam current correlated with sensor signal
- Electronics and readout
  - To allow individual operation without LHC signalling
  - DAQ triggering
  - Compact & modified wiring
  - Dedicated/upgraded VETRA software
- Mobility stand
  - Motorised, remote control
  - Precise movement
- Protective shrouds

Concept



Concept of measurement: Events from the beam halo are recorded by the sensors are correlated with the total beam current, then converted to dose delivered, online.

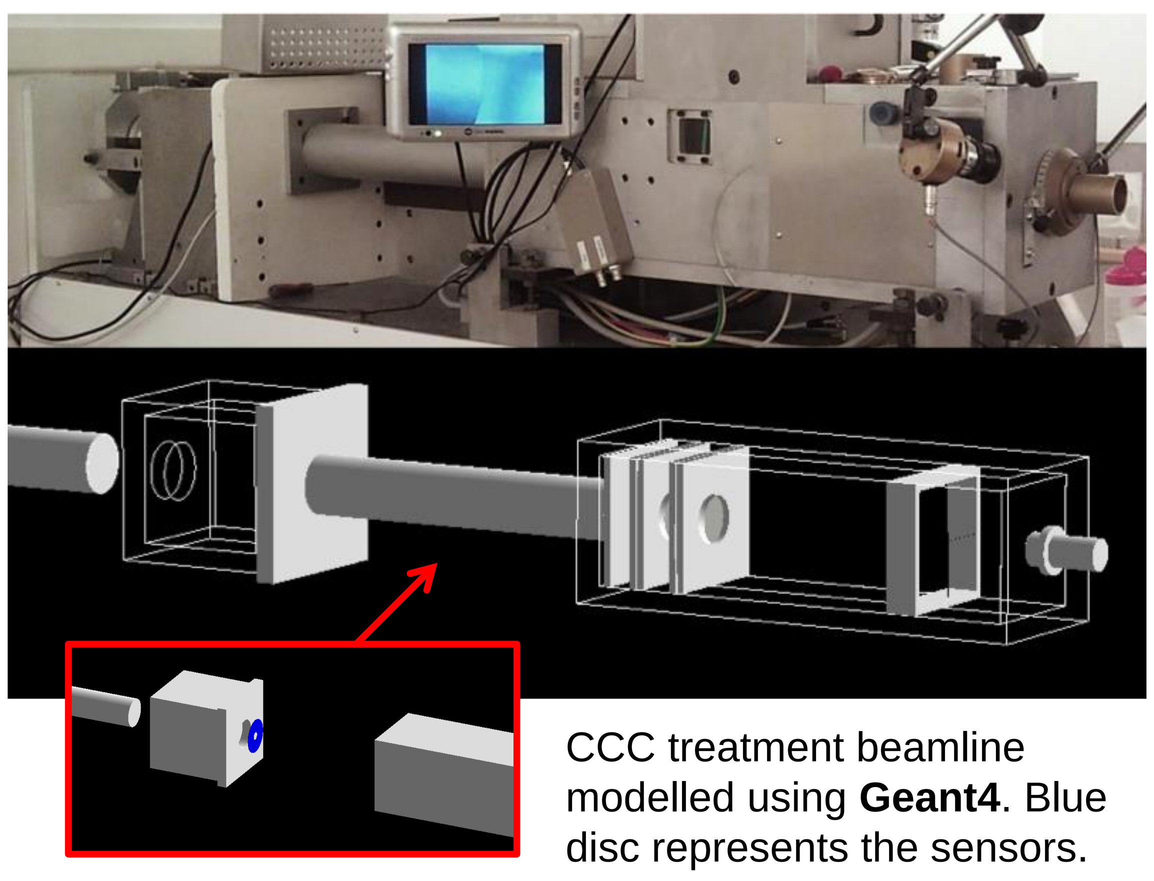
Integration in CCC



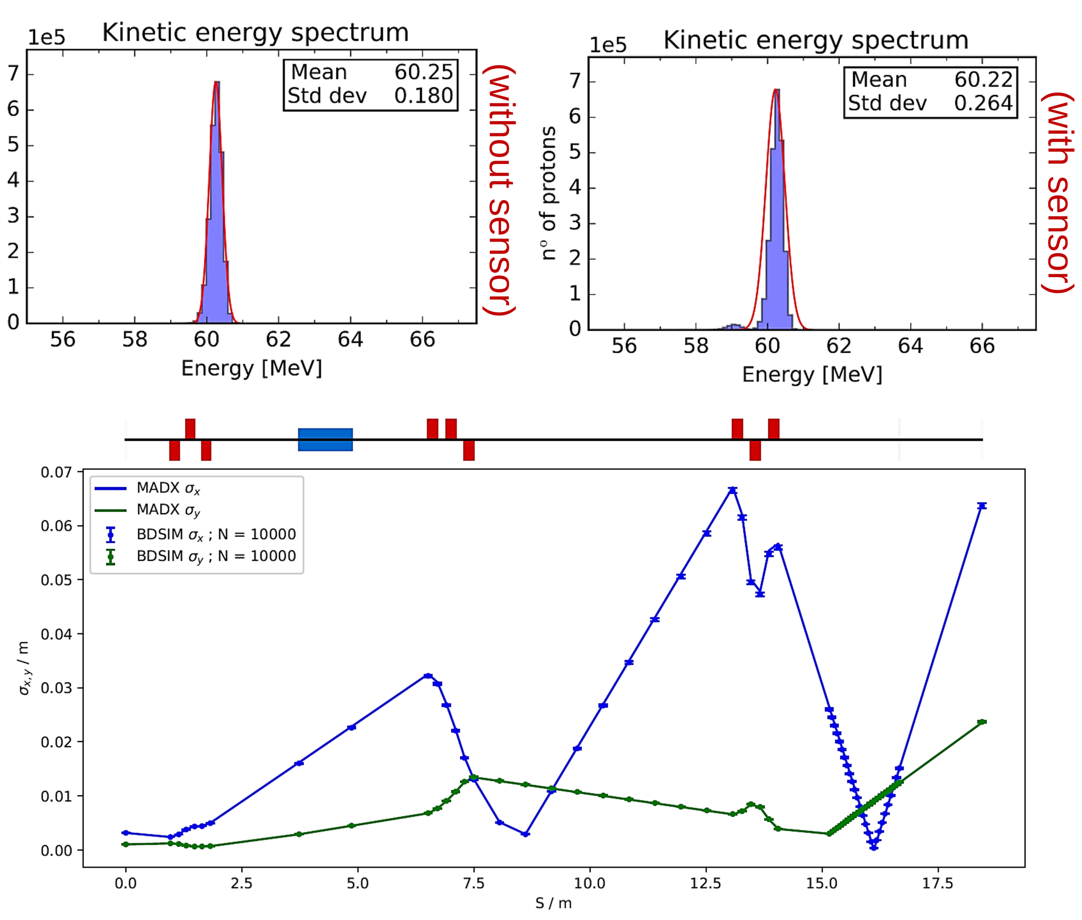
Readout process: an external pulse generator is needed to inject an **external trigger** into the TELL1 board to **synchronise** the 25.7MHz cyclotron RF frequency and proton bunch arrival with the fixed 40MHz VELO readout.

Simulation Studies

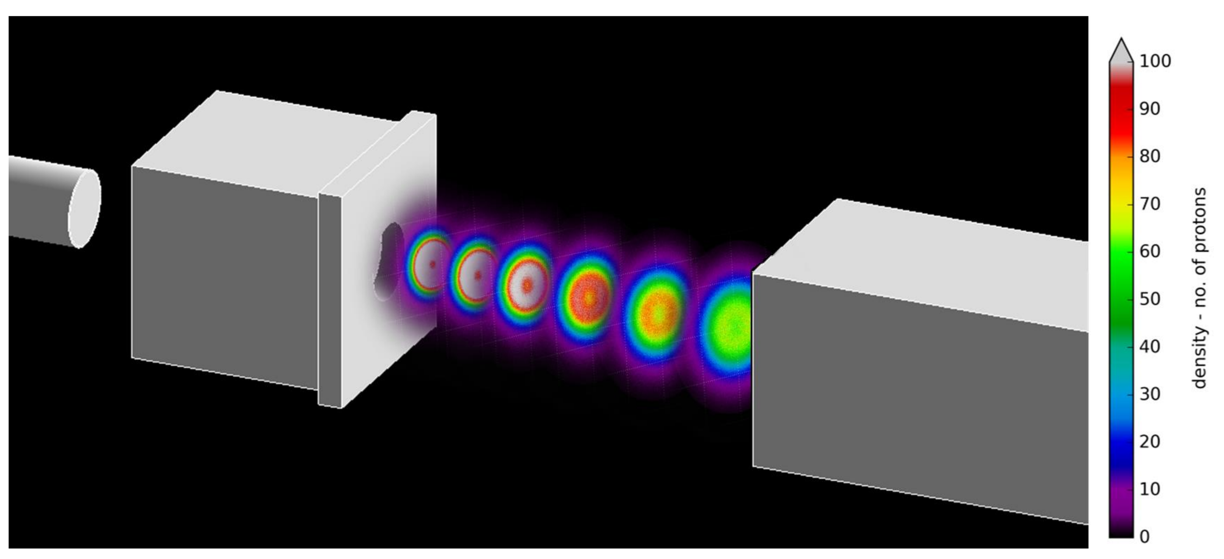
Simulations were performed to investigate the integration of the sensor and resulting effects on the beam.



CCC treatment beamline modelled using **Geant4**. Blue disc represents the sensors.



Halo Map Database



Beam transport simulations (left) using **MadX** & **BDSIM** provide optics parameters necessary for particle tracking and the complete combined simulation model. A **database of halo maps** according to different machine settings will yield relevant beam information as determined by online measurements with the VELO stand alone beam monitor.

Ongoing Developments & Outlook

First measurements with the beam monitoring system were achieved recently at the Birmingham MC40 cyclotron and further system improvements are planned before **testing at the Clatterbridge proton therapy beamline, expected for summer.**

Additional **film & emittance measurements** are also anticipated at Clatterbridge within the next months, to verify different aspects related to both the **optical lattice and Geant4 model**. It is intended that the inclusion of beam optics information in a finalised, complete model will be available for wide use as a **verified, standard simulation model** for all related work performed at the beamline.

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