

BDSIM Developments for Hadron Therapy Centre Applications





Proton therapy requires more complex and advanced technologies than classical radiotherapy and therefore leads to higher construction costs for the complete systems. The proton therapy centres were initially built with multiple treatments rooms sharing the proton beam.

The development of the future proton therapy centre aims to reduce construction cost by decreasing the centre size and by proposing single-room designs featuring compact gantries.

The reduction in size coupled with the increase of research efforts in the proton therapy centres leads to the increase of radiation to the system itself (accelerator, beamline, gantry and concrete shielding). **The overall activity of the centre will then be increased.**

Studies over a new type of concrete whose composition decreases the final quantity of radioactive waste after the centre decommissioning have started. **Detailed simulations regarding the overall activation must be realised.**

New methods have been developed to answer the new challenges that these ongoing studies pose for the numerical simulations that evaluate the beam properties, the radiation protection quantities, and the concrete shielding activation.

These challenges can be tackled by using the numerical beam transport and Monte-Carlo code Beam Delivery SIMulation (BDSIM) [1], a Geant4-based particle code, which allows a seamless simulation of the beam dynamics as a whole.

New developments have been carried out in BDSIM and its associated tools and libraries to advance its capabilities towards complete proton therapy system simulations.



[1] L. J. Nevay and al. BDSIM: An accelerator tracking code with particle-matter interactions. *Computer Physics Communications*, 2020.



The first new development is an improved 3D visualisation of the BDSIM model and its simulation results.

A **python toolbox** has been developed to provide **conversion mechanisms**, from the **Geant4 geometry format and ROOT data to 3D visualisation with the VTK framework [2]**. It supports the complex geometries used by the BDSIM models, the transported beam tracks, and the scored quantities.

An additional feature is the **possibility to directly import the converted files into Paraview** and save all the exported model elements into a Paraview state file (.pvsm).

[2] S. T. Boogert and al. *Pyg4ometry: A tool to create geometries for GEANT4, BDSIM, G4Beamline and FLUKA for particle loss and energy deposit studies. IPAC2019, 2019.*

[3] C. Hernalsteens and al. *A novel approach to seamless simulations of compact hadron therapy systems for self-consistent evaluation of dosimetric and radiation protection studies, European Physics Letters, 2021.*

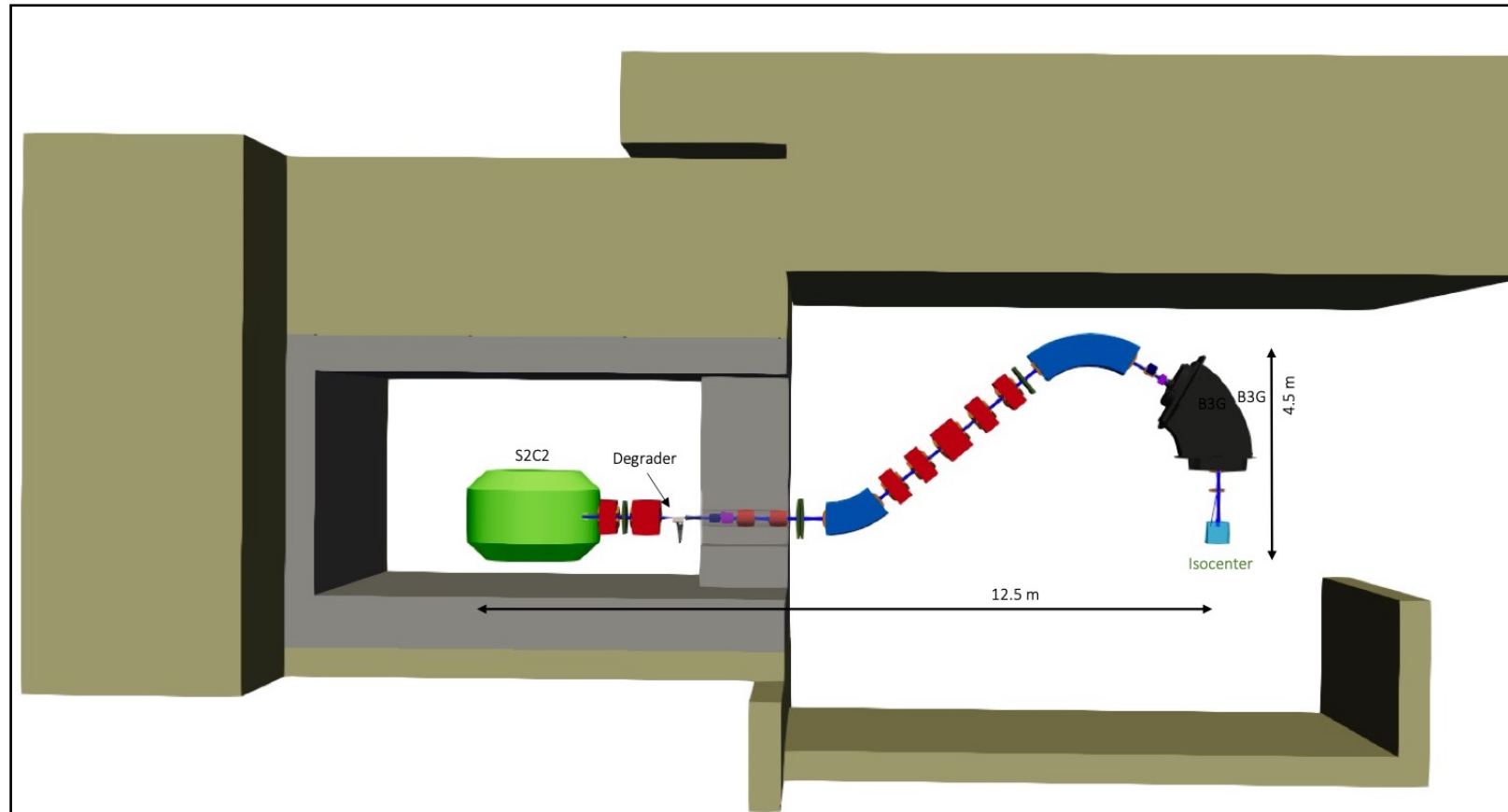
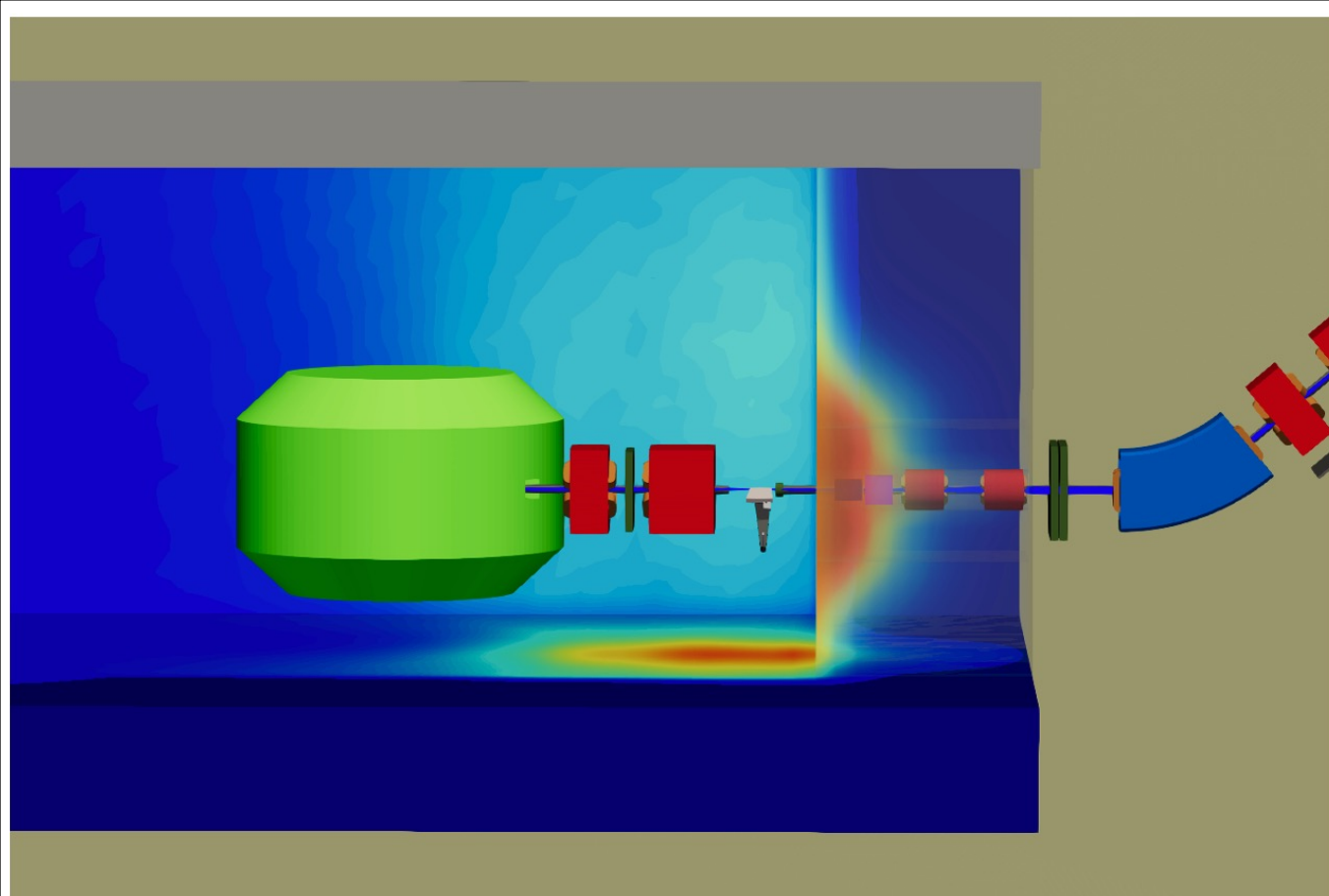


Figure 1 represents **the IBA Proteus One beamline [3] with its shielding and its primary proton beam** exported in VTK format in Paraview. The colour of the majority of the beamline elements follows the BDSIM colour code apart for the S2C2 (the accelerator), the degrader, which is a wheel composed of blocks of different thicknesses of three varied materials: Aluminium, Graphite and Beryllium, and the third bending magnet B3G.

The concrete shielding is represented with two distinct colours to highlight the presence of two different types of concrete in the shielding walls.



The shielding activation finds its origin in the secondary neutrons nuclear reactions (capture or spallation) inside the concrete walls. Their production is induced by the collisions of the primary beam with the degrader [4].

The secondary neutrons fluxes can be extracted from the BDSIM simulations and integrated into Paraview by conversion of the resulting ROOT histograms into VTK format.

Figure 2 represents the results of such an extraction: the secondary neutrons fluence scoring data is visualised inside the Paraview model.

The “surface” visualisation has been chosen for the back wall and the floor while the “volume” visualisation has been chosen for the part of the beamline passing through the concrete shielding linking the vault where the accelerator lies and the treatment room.

The 3D observation of the secondary fluxes results shows hotspots in the area around the degrader which would typically be zones of interest for a thorough activation computation.

[4] R. Tesse Numerical simulations to evaluate and compare the performances of existing and novel degrader materials for proton therapy. *Journal of Physics: Conference Series*, 2018.



In addition to displaying the BDSIM results in a 3D model, a great number of other visualisation tools are available to optimise the way the results are presented such as the **possibility to directly include DICOM files to visualise the patient scans slice by slice or with a volume rendering.**

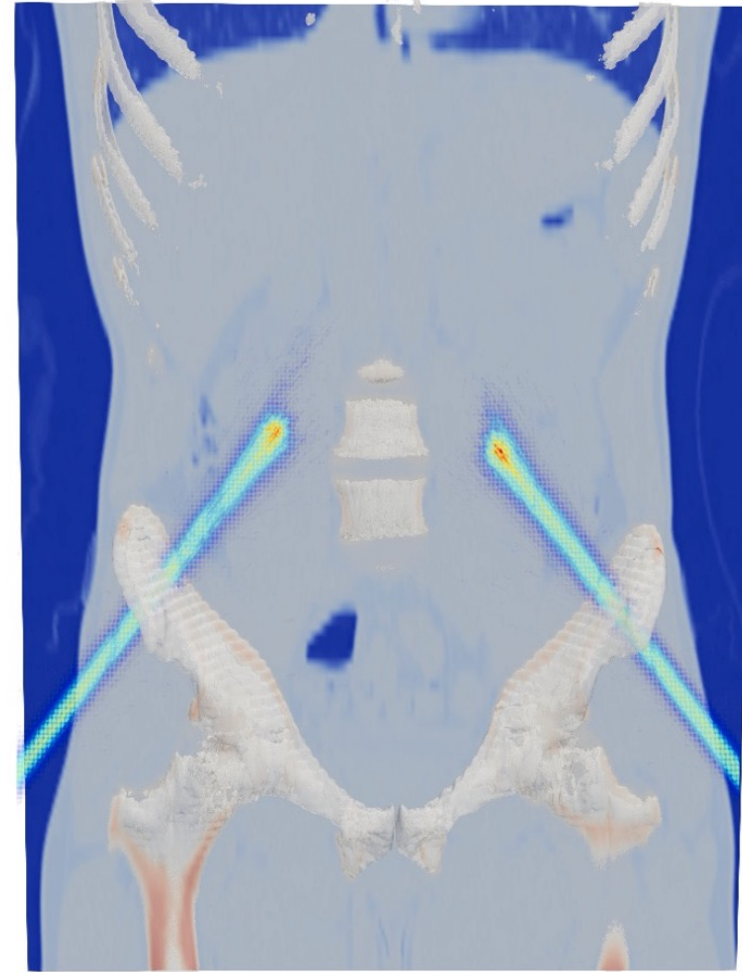


Figure 3 illustrates the added value of using Paraview as viewer for BDSIM with the visualisation of two protons beams interacting in a phantom.



The second new development concerns a new tool for extracting the differential particle fluence from the BDSIM simulations.

More precise activation results can be obtained by coupling the Monte Carlo code BDSIM with the code system and library database FISPACT-II.

FISPACT-II allows a thorough calculation of the shielding activation in the form of inventories and radiological output computations.

As input information, **FISPACT-II requires the differential particles fluxes** following some predefined group structures (e.g., CCFE-709, UKAEA-1102, etc.).

The new feature is a detailed 4D Monte Carlo scoring mechanism that produces tallies such as spatial-energy differential fluence in arbitrary scoring meshes.

This feature makes use of the generic boost::histogram library and allows an event-by-event serialisation and storage in the ROOT data format.

The differential fluxes extracted by the **new 4D scoring combined with conversion coefficients** can be used to quickly compute radiological quantities without needing a new BDSIM simulation.

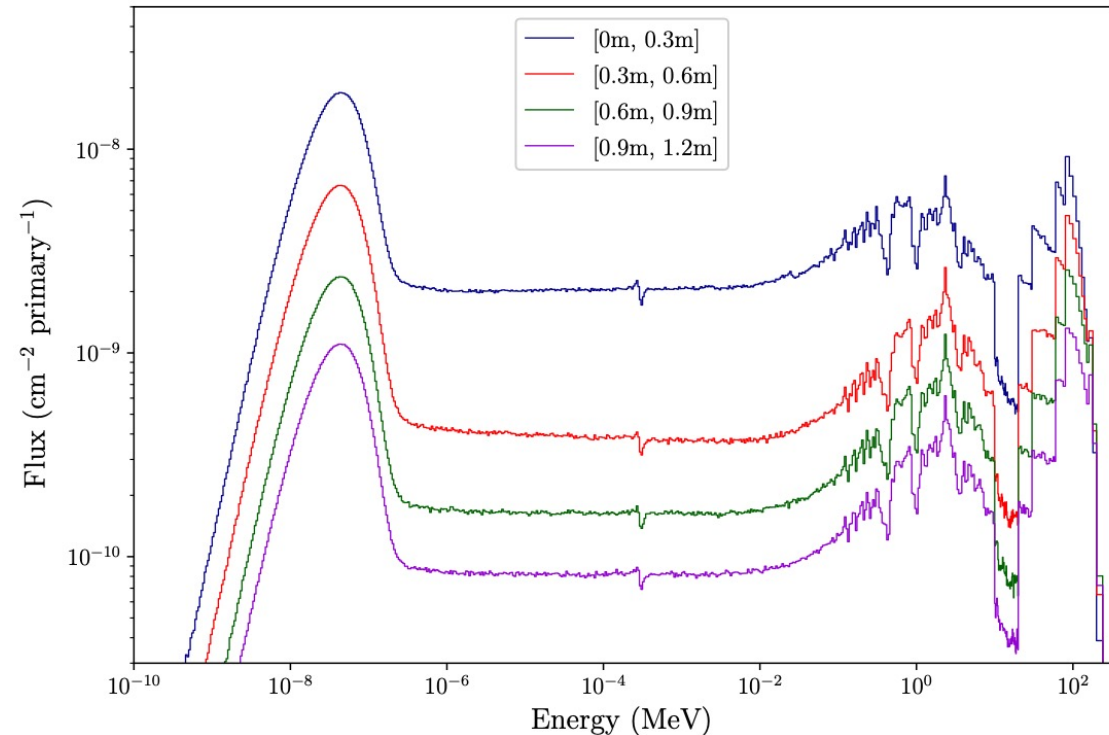


Figure 4 illustrates the new 4D scoring feature. The differential fluence has been computed for the right-hand side wall of the degrader following the CCFE-709 energy group structure binning of the FISPACT-II nuclear data libraries and with four bins along the wall thickness.



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