

Comparison of boron carbide and graphite energy degraders for proton therapy facility

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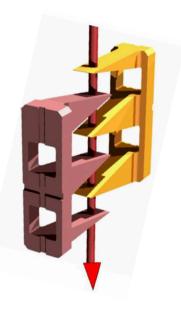


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MOTIVATION

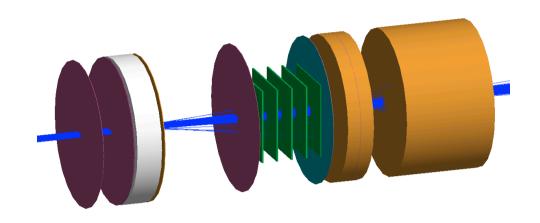
Cyclotron-based proton therapy centres require a beam energy degrader so that the constant kinetic energy of the beam extracted from the accelerator is adjusted according to the clinical treatment plan. It is conventionally done by a low-Z, high density material of variable thickness. Simultaneously to energy reduction, both energy spread and emittance increase, due to interactions with the material. This in turn causes transmission losses, as the energy degrader is usually followed by a system of collimators and energy selection system (ESS). The negative effects can be potentially reduced by replacing graphite with a boron carbide (B₄C) degrader. In this project, a real geometry wedge degrader is considered and Monte Carlo simulations are benchmarked against measurements in the Centre for Proton Therapy (CPT) at Paul Scherrer Institute (PSI) in Villigen, Switzerland.

ENERGY DEGRADER AT PSI



The energy degrader currently used at PSI is made of two sets of 3 wedges each (2 full wedges and one half wedge) which are inserted to the beamline depending on the kinetic energy required by the treatment plan. The degrader is then followed by collimators to reduce beam size and angle, and subsequently by energy selection system to choose the correct energy and energy spread.

SIMULATIONS



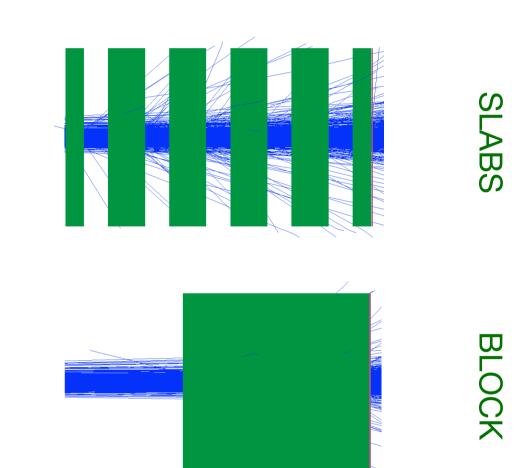
Monte Carlo simulations were performed in G4Beamline, Geant4-based program for beamline simulations. The increase of beam emittance in the degrader material is mostly due to Multiple Coulomb Scattering for which multiple analytical calculations could be performed. However, Monte Carlo simulations include more complex processes and allow for transmission calculations which is one of the major goals of this work.

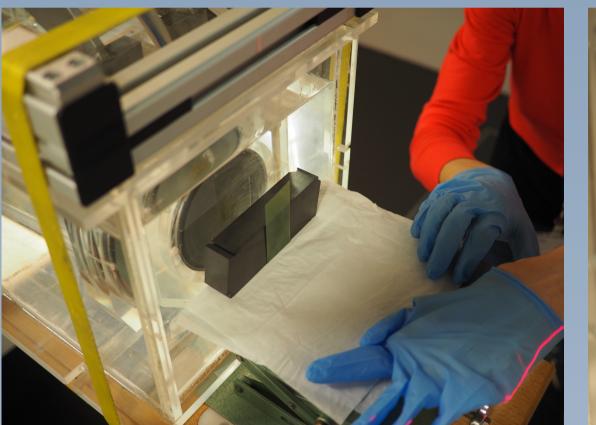
DEGRADER MATERIALS

Name	Density [g/cm³]	Z _{eff}	Ion. potential [eV]
Graphite	1.87	6.0	77
Boron carbide	2.53	5.3	85

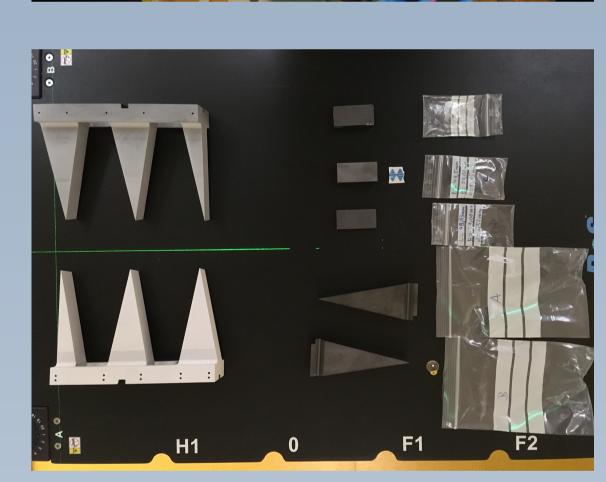
DEGRADER GEOMETRIES

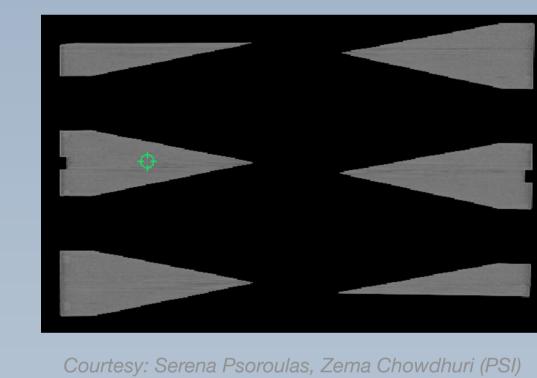
Two geometries of the degrader are considered: a block and multiple slabs. Slabs geometry was chosen to simplify the simulations after having verified that no difference in beam characteristics is observed when wedges and slabs are compared.











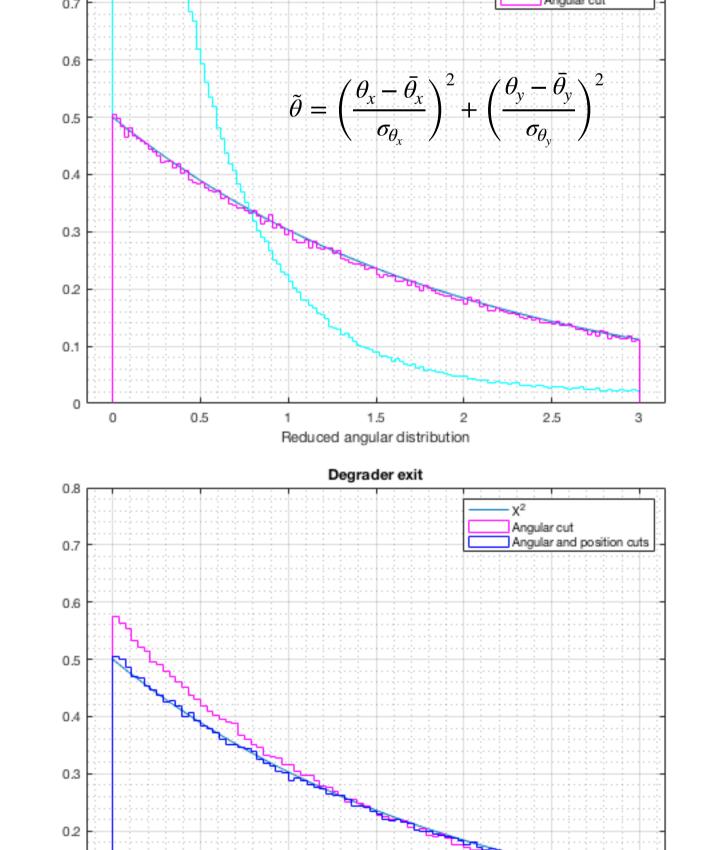
Measurements of the two materials samples and spare wedges were performed to determine their density, homogeneity and ionisation potential

for G4BL simulations.

EMITTANCE DEFINITION

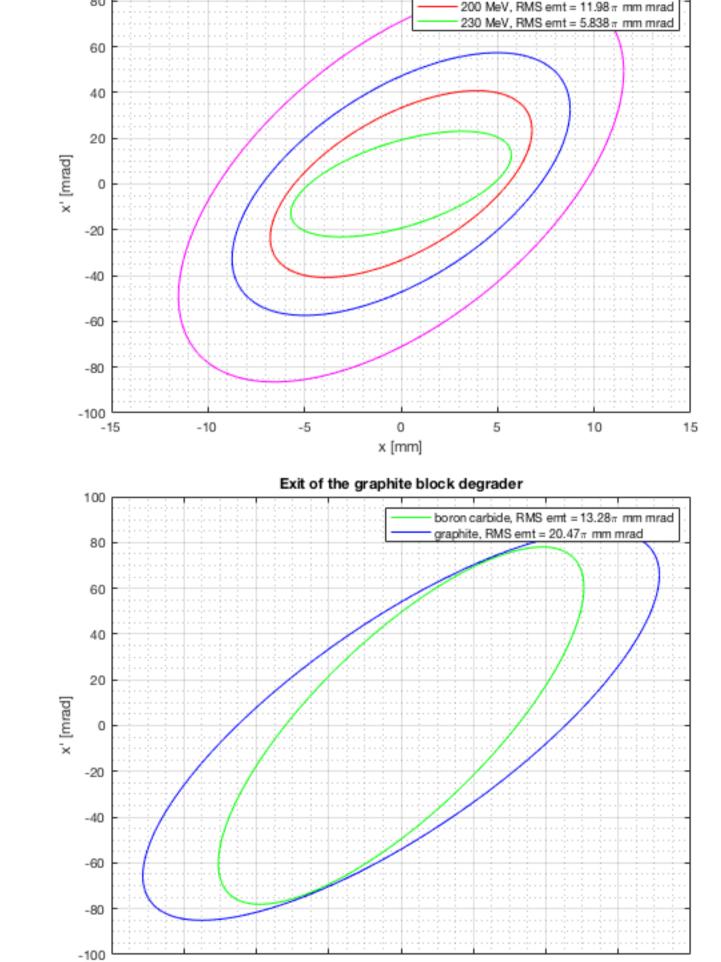
In order to reliably compare beam characteristics at the degrader exit, a way of emittance calculation was determined. The method used extracts the Gaussian core of the beam in position and angular distributions. This is based on the assumption that the tail particles removed from the beam for the emittance calculation would be anyhow lost in the following collimators and ESS.

Original distribution



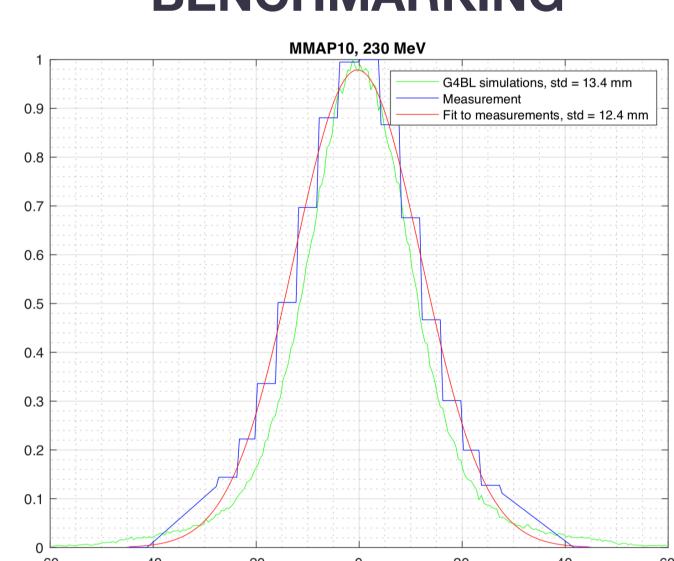
Reduced position distribution

Degrader exit



Exit of the graphite block degrader

BENCHMARKING



Vertical position distribution for a 230 MeV beam after the degrader (MMAP10): G4BL simulations (green) are benchmarked with measurements (blue) with a Gaussian fit (blue).

FUTURE WORK

Both graphite and boron carbide wedge degraders placed in the real beam line at PSI have been recently used for beam measurements (profile, emittance). The results are now to be analysed and benchmarked against the Monte Carlo simulations.

REFERENCES

- [1] Van Goethem, M. J., et al. "Geant4 simulations of proton beam transport through a carbon or beryllium degrader and following a beam line." Physics in Medicine & Biology 54.19 (2009): 5831.
- [2] Gerbershagen, Alexander, et al. "Measurements and simulations of boron carbide as degrader material for proton therapy." Physics in Medicine & Biology 61.14 (2016): N337.
- [3] Tesse, Robin, et al. "Numerical Simulations to Evaluate and Compare the Performances of Existing and Novel Degrader Materials for Proton Therapy." Journal of Physics: Conference Series. Vol. 1067. No. 9. IOP Publishing, 2018.

